POWER PLANT ENGINEERING

Established Over 35 Years

VOL. XXXV CHICAGO, JANUARY 1, 1931 No. 1

EDITORIAL STAFF — ARTHUR L. RICE, Editor; R. E. TURNER, Managing Editor; A. W. KRAMER, Associate Editor; CHESTER R. EARLE, Associate Editor; RICHARD H. MORRIS, Associate Editor; EDWARD J. KUNZE, Associate Editor

Power Distribution and Utilization Number

Page

Economy in Heat and Power. By C. C. Wilcox..... 2
Loss by cold air leaks, hot air waste, pipe leakage and radiation, also excess fan power, too large motors, lamp breakage and just plain dirtiness.

Calculating Steam Pipe Sizes and Pressure Losses..... 8
Allowable pressure drop is usually the determining factor.

Building Flexibility Into the Steam Line..... 9

Valves and Fittings in the Pipe System..... 11
Friction loss through valves and fittings, reducing valve layout and service outlets.

Calculating Heat Losses from Insulated Lines..... 13

Capacity of Water Pipe Systems..... 14
Principles governing flow of water in pipe, factors that cause loss of head, water hammer.

Controlling Flow of Water..... 16
Changing speed of pump and use of suitable valves in suction and discharge lines are means of regulating water flow.

Storage of Water in Industrial Plants..... 18

Compressed Air Distribution..... 20
Air Flow Calculation. Factors that affect velocity, pressure and quantity of flow.

Regulation of Compressed Air..... 21
Control of air compressor speeds, application of unloaders. Moisture removal methods.

Compressed Air Storage..... 23

The Possibilities of America as Seen by Steinmetz..... 24

Electrical Distribution Systems. By Ottomar H. Henschel 25
Types and precautions for safety and economy.

Electrical Distribution Circuit Practice..... 28
Maintenance of wiring. Determination of load current, conductor size, voltage drop.

Switchboard Construction and Arrangement..... 31

Bus Bar Design and Construction..... 34

Switchboard Equipment..... 35

Methods of Voltage Control..... 37
Rheostats and mounting. Auto transformers, automatic voltage regulators.

Switchboard Instruments..... 39

Principles of Transformer Action..... 40
Discussion of inductive relations, voltage and current ratios, effects, resistance losses, frequencies, transformation.

Fundamentals of Transformer Construction..... 42

System of Transformer Connections..... 44
Internal and external connections for various voltage and current combinations.

Uses of Transformers..... 46

Design Factors for Systems of Power Distribution. By Chancey S. Millard..... 47
Individual requirements of different types of buildings and industries requiring steam, and electrical and mechanical power are considered as separate problems.

Transmission of Power by Means of Shafting..... 50

Power Transmission by Various Types of Belts..... 53
Characteristics of materials and arrangements of various types of belting.

Types of Gears for Industrial Use..... 59

Fundamentals of Common Gear Tooth Design..... 60
Involute form commonly used with stub and uneven addendum tooth gaining in popularity.

Good Gears Have Small Friction Losses..... 61
Modern Herringbone gears show efficiency ranging from 97 to 99 per cent.

Speed Ratios and Size of Gearing..... 62

Speed Changers and Variators for Shaft Drives..... 63
High ratios of speed transformation which came with turbines and motors are accomplished by geared units.

Power Production, Distribution and Use in Large Industrial Plants. By Dan Gutleben..... 66
Economies in steam generation, current, heat service, compressed air, electrical and mechanical transmission and drives.

Calculating Heat Losses from Building..... 69

Determination of Direct Radiation Needs..... 69
Surface and steam requirements for heating elements placed in the room.

Indirect Heaters..... 71
Indirect heaters in which the heat transfer is entirely by convection are popular.

Hot-Water Heating for Buildings..... 71

Power and Heat Requirements for Air Conditioning.... 73
Pumps, fans, filters and heaters requiring plant service in laundering air.

Steam for Process Work in Industrial Plants..... 75
Amounts, pressures and temperatures of steam used in textile, paper, food, laundry, hotel and other industries.

Hot Water for Industrial Processes..... 78
Data from typical industrial plants showing amounts and temperatures of water for various uses.

Water Uses for Plant Supply System..... 79

Uses of Water in Process Work..... 82
Water is an important factor in many processes.

Compressed Air Industrial Uses..... 83
Application of compressed air to tools, hoists, blowing and sprinkling service.

Power Use and Human Progress. By Harry W. Benton 88

Electric Motors for Industrial Plant Drives..... 89
Direct current motors, types and characteristics.

Alternating Current Motors..... 91
Types and characteristics, speed control, motor troubles and tests.

Synchronous Condensers and Capacitors..... 93
Correction of low power factor by means of synchronous or static condensers.

Adequate Lighting Increases Production..... 95
Fundamentals of artificial illumination practice dictate suitable quality, proper direction and correct amount of light. Lighting standards steadily improving.

Application of Electric Heat in Industry..... 98
Economies of electric heating. Principles involved, methods of production, electric furnace constructions.

Application of Enclosed Electrical Resistors..... 101

Mechanical Engineers' Fifty-first Annual Meeting..... 103
Human problems along with material handling, hydraulics, fuels and central station power occupied interest of A.S.M.E. members at New York, December 1 to 5.

Editorial Comment: Workers and Jobs. New Principles in Power Plant Design. Smoke Abatement and Human Factors. Acknowledgment..... 108

Ninth Exposition of Power and Engineering..... 110

C. E. Allen Appointed Commercial Vice-President for Westinghouse Elec. & Mfg. Co..... 120

News Notes..... 120

Published on the 1st and 15th of each Month by the

Technical Publishing Co., 53 West Jackson Blvd., Chicago

New York Office, 171 Madison Avenue

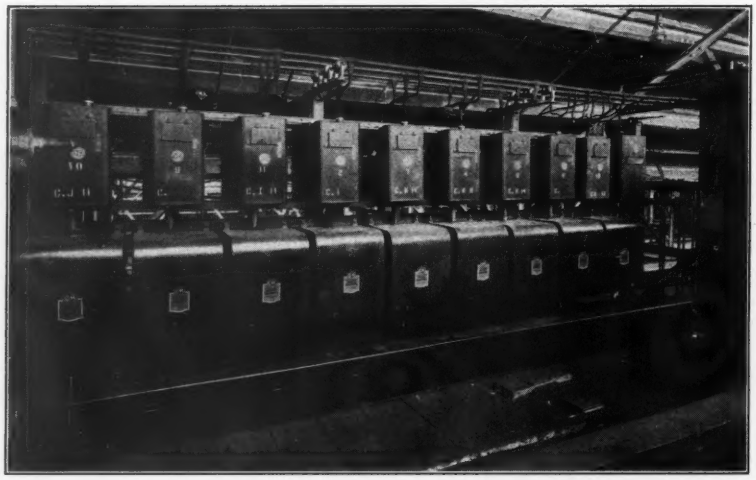
Subscription price $2.00 a year in the United States and possessions. Canada $2.75 a year. Other countries $3.50 a year. Single copies 15 cents.
Copyright 1931, by Technical Publishing Co.
Entered as second class matter May 1, 1908, at the Post Office at Chicago, Illinois, under the Act of March 3, 1879.

Member, Associated Business Papers, Audit Bureau of Circulations.

Circulation of this issue 24,300

ECONOMY IN HEAT

Loss By Cold Air Waste, Radiation, Too Large age and Just



Production line starters are placed in groups on balconies

WHEN EFFORTS are being redoubled to increase profits, it is logical to ascertain first the most fertile field in which to work and it is usually a safe assumption that it lies in the distribution and utilization of service, because supervision over a wide territory is difficult whereas it is easy in the comparatively concentrated operation of a power plant. Distribution and utilization losses are as a rule widely scattered, the individual losses comparatively small and the number of locations large, so that, even though the losses in the aggregate are considerable, they are less easily isolated and brought to the attention of the management, hence their importance is often underestimated.

Long ago the Studebaker corporation recognized the above principles and considerable progress has been made in the reduction of preventable distribution and utilization losses. The following, therefore, is largely an analysis of conditions existing in that plant, although applicable for the most part in any large industrial plant whose manufacturing operations require the use of steam, electricity and air. For purposes of comparison the following plant characteristics will be valuable:

Acres covered by plant	125
Distance from power plant to end of longest steam line, ft.	2600
Total contents of buildings, cu. ft.	100,685,000
Total of equivalent direct steam radiation, sq. ft.	1,949,900
Connected load—light-kw.	6700
Connected load—power-kw.	36,000
Steam generated per year, 1000 lb	2,541,000
Max. boiler load—lb. stm. per hr.	677,000
Kw-hr. generated per year	45,375,000
Kw-hr. purchased	4,528,000
No. electric motors connected	5400
Generated peak, kw.	14,750
Purchased peak, kw.	2200
Air compressor capacity—c.f.m. at 100 lb	28,475
Air compressor capacity—c.f.m. at 40 lb	5400
Air per year—M. cu. ft at 100 lb.	3,241,000
Air per year—M. cu. ft. at 40 lb	85,500
Total coal burned—tons	144,000

Figures above show the order of magnitude of the quantities involved, and the plan in the headpiece gives an idea of the distribution of buildings and tunnels.

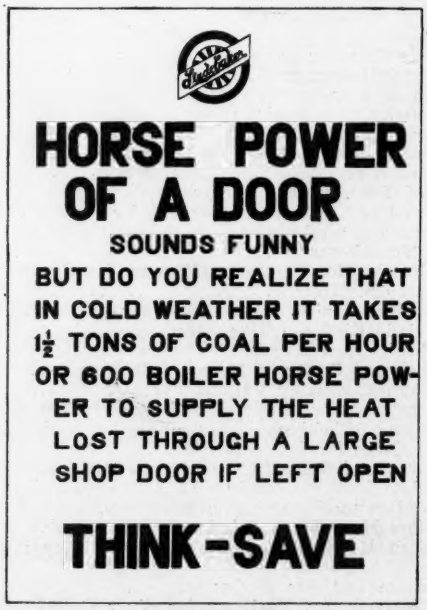
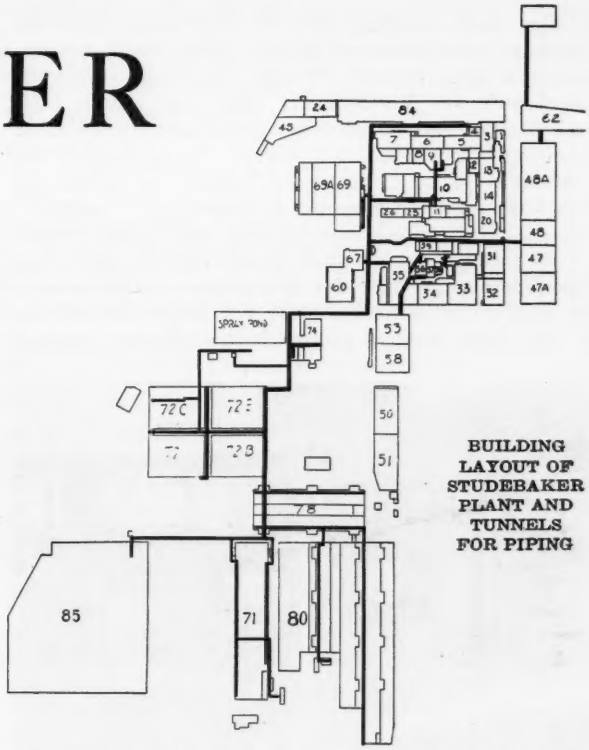

HORSE POWER OF A DOOR
SOUNDS FUNNY
BUT DO YOU REALIZE THAT
IN COLD WEATHER IT TAKES
1½ TONS OF COAL PER HOUR
OR 600 BOILER HORSE POWER TO SUPPLY THE HEAT
LOST THROUGH A LARGE
SHOP DOOR IF LEFT OPEN
THINK-SAVE

FIG. 2. GOOD FOR A THOUGHT AROUSER

AND POWER

Air Leaks, By Heated By Pipe Leakage and Also Excess Fan Power, Motors, Lamp Break-Plain Dirtiness . . . . .

By C. C. Wilcox



BUILDING LAYOUT OF STUDEBAKER PLANT AND TUNNELS FOR PIPING

In an extensive plant having a large amount of exhaust steam available from manufacturing operations and a large heating system requiring steam, so long as live steam make-up is required for the heating system, a saving in compressed air, for instance, which is furnished by compressors exhausting to the heating system will effect little or no saving in coal used in the boiler room. There may be considerable periods, when the only, or at least by far the most effective method of reducing the demand on boilers is to conserve heat; furthermore, there is never a time but that a saving in heating requirements will effect a reduction of boiler load. This point is stressed because it points the way to the most fertile field for reduction of losses and costs.

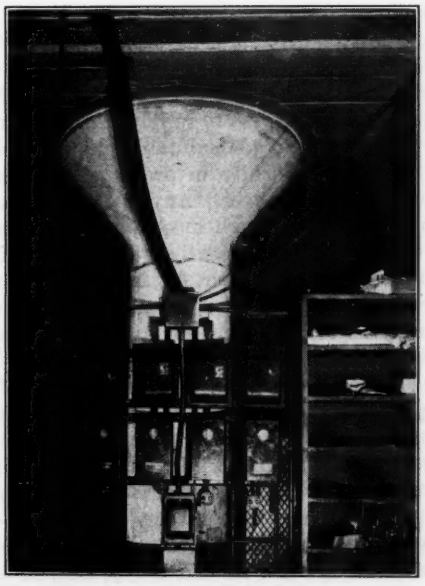


FIG. 3. SEMI-PERMANENT MOTOR STARTER

Obviously, the open window with the radiator turned on is as a rule a preventable loss but it is a common and persistent condition. In this plant one man is specially assigned to watch and correct this and other losses of heat. He shows a good profit.

In some locations a change of manufacturing operations will result in an excess radiation connected. The safest thing to do in this case is to disconnect enough so that there will be no excess for coldest weather conditions. Oftentimes, radiator valve handles will be defective or missing, which may result in overheating, or in the open window.

Cold Air Leaks

Liberal use of conveyors, which is so necessary to the efficient handling of material often results in openings through outside walls for operation of the conveyor, resulting in infiltration of cold air at such points. Wherever it is impractical to close up the opening, an air lock should be included in the layout when the conveyor is installed.

It is worthwhile to give serious thought to the method of closing large shop doors, particularly those frequently used. For the passage of motor-operated vehicles, it works out nicely to install an electric, or air-operated door which can be opened and closed by the driver without leaving his seat. Doors through which locomotives enter are necessarily large and present quite a problem in keeping tight, especially at the track level. It is surprising the amount of heat which is dissipated in cold weather by the opening of a large shop door. Figure 2 is a notice which has been used with good effect.

One most annoying waste of heat occurs from the necessary ventilation of lacquer spray booths, maintained at approximately 70 deg. The fans handle between 5000 and 10,000 cu. ft. of air per minute each and the large number of them means that a considerable amount of heat is lost in this way. It would seem that some type of heat interchanger could be applied by which the incoming air could be heated by the outgoing air without drawing obnoxious gases back into the room. Studebaker has already built one of these for trial. Any heat interchanger used for this purpose would have to be installed in individual units attached to the various outlets rather than a central heat exchanger, because

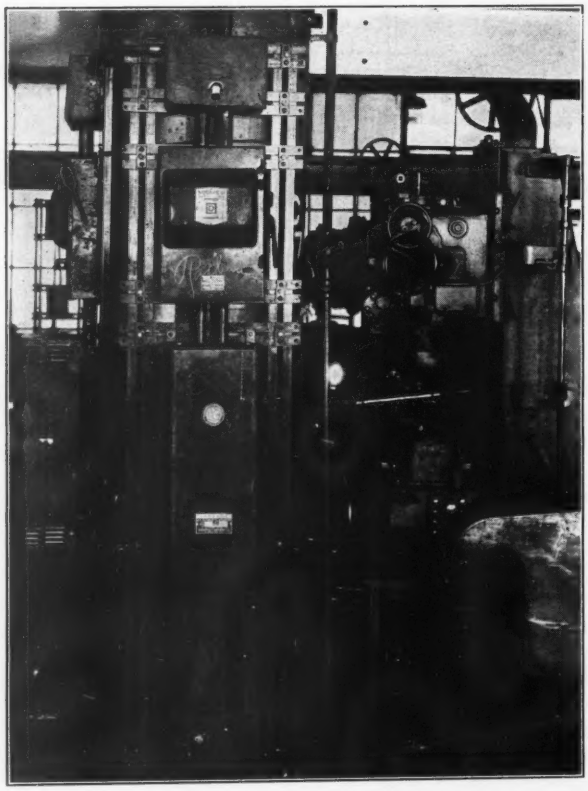


FIG. 4. PERMANENT MOTORS HAVE STARTERS MOUNTED ON STANDARD RACKS

of the danger of communication of fire from one spray booth to another, if these outlets were interconnected.

7000 cu. ft. of air per minute heated from 0 to 70 deg. represents 17.5 boiler horsepower, approximately, and, since this loss usually occurs at the time of the maximum boiler load, it would seem to be sound engineering to install such a device rather than to purchase boiler capacity to supply the loss, if the cost of such a unit can be made to approximate that of equivalent boiler capacity. The savings effected by conservation of heat would then be net gain.

Tunnel Pipe Line Radiation

Often it is found that the closing of individual riser valves, or throttle valves on miscellaneous equipment using steam will effect less reduction in steam send-out to lines supplying these uses than might be expected; the difference is the steam consumed by radiation from the tunnel lines, that lost in steam traps and the like. In other words, it is better to shut off main lines in the tunnel rather than to shut down individual departments. The relative amounts of steam consumed in the two methods of shutting down should be thoroughly discussed with the heads of those departments wishing to run on week-ends or holidays, so that those responsible for production will understand just what it costs to run one or two isolated departments, if it means keeping the tunnel steam lines built up. Recently, we saw a case where the operation of one hammer required sufficient tunnel and distribution lines to be built up so that the steam send-out to this line was in excess of 40,000 lb. per hour, most of which could have been eliminated had it not been necessary to run the one hammer. Careful thought should be given by the management to the coördination of all departments so that the maximum savings can be made on week-ends and holidays when the plant as a whole is shut down.

Main line piping, at least is usually adequately covered. It is surprising, however, how much heat is dissipated by the comparatively small trap lines which many times are uncovered. A good procedure is to make a moulded cover for the trap, reënforced with chicken wire; built in two parts so that the top can be lifted off for trap inspection and the halves neatly finished with duck and painted for protection. This procedure is particularly desirable in tunnels or exposed places where the comfort of workmen, as well as the heat loss which would otherwise be sustained, is involved.

Leaks and Waste

One of the most powerful tools in the hands of the power department for the reduction of steam leaks is the practice of welding. This is becoming more and more general and cannot be too highly recommended. In this plant, welding is used almost exclusively in all pipe sizes from ½-in. up.

No power department can effect maximum saving in the use of steam without the full coöperation of production departments. One sure way of discouraging this coöperation is to have valves for the control of the service to individual steam-using devices inconveniently located or improperly maintained so that they cannot be completely shut off, while an effective way of building up an esprit de corps is to supply these conveniences.

One great obstacle to maintaining valves tight in steam lines is the difficulty in properly treating boiler water to prevent carry-over. Any method of treatment which goes only far enough to eliminate the formation of hard scale in boilers is less than 50 per cent effective, unless it prevents carry-over, because more damage is done by solids being carried over into steam turbines and into the miles of steam pipe and hundreds of traps than is caused by the necessity of boring tubes in the boiler room.

Long lines of steam require, of course, some provision for taking care of expansion and, for this purpose, a number of well-designed expansion joints are on the market. The so-called slip joint has been the most popular for high pressure but it requires packing. A 12-in. expansion joint requires approximately $50 worth of packing when the old is replaced, in addition to the labor cost, which is often considerable. Expansion joints are usually found in crowded quarters so that

C. C. Wilcox, during his course at Ohio State University, engaged on construction and repair work with Columbus, O., Railway & Light Co. and completed his work for M. E. in 1903. As engineer on operation, design and construction with Bartlett Illuminating Co., Saginaw, Mich., he gained experience from 1903-1905, then went with Tennessee Coal, Iron & RR. Co. on rehabilitation and operation of blowing engine plants for blast furnaces and power plants for mines and rolling mills. Turning in 1906 to educational work, he carried on investigations of insulators at O. S. U., leading to the degree of E. E., then went to Michigan Agricultural College in charge of shops and steam engineering courses until 1910. With Hodenpyl, Hardy & Co., Inc., he was for 9 yr. in charge of construction and operation in various cities of plants of all types aggregating 160,000 kw. capacity and carrying 2,000,000 sq. ft. of heating radiation. As chief engineer of General Motors Building Corp., Mr. Wilcox had charge of design of plants and selection of equipment for the Detroit and New York buildings and of creating the operating organizations. In 1922 he went with Studebaker Corp. as superintendent of the power division in charge of power and heating for all plants.

repacking them is an uninviting job for the maintenance man and is likely to be neglected. This results in leakage of steam into the tunnel and makes the job of packing still more unpleasant. Where space is available, a satisfactory remedy for this is to install an expansion loop in place of the expansion joint. Where space is not available for the loop, an expansion joint must be used, preferably one in which the sleeve is mechanically guided rather than the packing and gland alone used for guidance. The combination of expansion loops and gas welding will provide a steam line which is free from repair for all time, unless it be injured by outside agencies.

Bad effects of tunnel leaks are cumulative. One bad leak, if allowed to continue, soon produces such a condition that maintenance can hardly be carried on and sometimes will make it impossible to get to a shut-off valve which must be operated to take care of some other case of maintenance. Take care of these troubles as they arise, because, if they become too numerous, a plant interruption becomes inevitable in order to make necessary repairs.

Being oftentimes difficult of inspection, a tunnel system may get dirty. This, with an inadequate lighting system will certainly lead to poor maintenance and the existence of losses over long periods before being discovered or corrected. It is unnecessary to go to great expense in cleaning a pipe tunnel but it should be done sufficiently well to satisfy the conditions of dollar efficiency. The maintenance man at all times should keep his tunnel in such shape that he is not ashamed to ask the manager or critical visitor to walk through it.

Live Steam for Heating

Where it is necessary to inject live steam into the heating system, this can best be accomplished by suitable control in the power plant, since this permits the most intelligent operation of mixed pressure turbines. Where exhaust or low-pressure steam piping has fallen behind the building program, or the lines are so long that it is expedient to furnish a little live steam at the extreme end of these lines to avoid excessive extraction pressure at the power plant, it is necessary that this be under control which will take care of the remote points alone without backing steam up through the exhaust main to other parts of the factory. For this purpose a master control has been used which, when the exhaust pressure at the end of the line drops to a pre-determined point, closes the exhaust steam valve entirely and opens up the live steam valve to maintain the desired pressure. As soon as the pressure ahead of the exhaust valve is raised to a certain pre-determined point, the operation is reversed and that part of the system goes onto exhaust steam operation again. This satisfactory method of admitting live steam permits the maximum amount of energy to be generated by steam extracted from the turbine.

Water and Air

In plants where only limited supply of water is available, some attention should be devoted to conservation of water. While the amount of money which may be wasted through this channel is usually less than that through steam or electric energy, it nevertheless may be considerable. Abolition of the drinking cup has resulted in practically universal adoption of the bubbling fountain. A good type is one which has a "sneak feed" and a self-closing valve. The "sneak feed" is adjustable and allows only enough water to pass the fountain to maintain the desired temperature, the self-closing valve being used for drinking only. This is, however, open to the objection that the "sneak feed" can be adjusted to wide open, or the self-closing valve tied open. A recent survey of the Studebaker plant showed that approximately 20 per cent of all the water used was consumed in the drinking fountains, because they operate 24 hr. a day unless special arrangements are made to shut them off, which is hardly possible for so large a number of fountains.

Conservation of compressed air presents problems peculiar to itself. Leaks can scarcely be detected by their noise while the plant is running and for this purpose the plant should be patrolled on week ends. Frying of air leaks when the machinery is silent is a familiar sound to most plant engineers. Occasionally it is a good plan to continue running a compressor after the plant is shut down in order to determine the magnitude of these leaks in the aggregate. This gives an idea of the progress which has been made in stopping leaks.

Electrical System

It sometimes happens that the growth of a factory leaves in its wake cases of under or over motoring, or pieces of apparatus which have become either too large or too small for the new service they are to perform. This is true of machine shop group drive, for instance, and is particularly true of shavings handling systems.

Waste Fan Power

In the case of group drive in the machine shop, it is comparatively simple to replace a large motor with a

small one, or vice-versa but a shavings handling system, designed for the carrying of a certain amount of material is laid out with fan sizes to carry a specified quantity of air. Fans are connected through the primary dust collecting lines to the machines, with collector piping having diameters designed to carry a definite supply of air handled by the fan or fans.

If woodworking machinery is added to or removed from the system, it is, as a rule, impossible to close up the openings which served the machines that have been removed, because to do so would result in decrease in the amount of air drawn in by the fans, thus reducing the velocity of air in the conveyor piping and resulting in the sedimentation of material in these pipe lines, until a new area is established which will restore the required velocity. Because of the danger of plugging up the conveyor piping, it becomes necessary to leave these openings to keep the air velocity as originally designed, even though the amount of material handled has been greatly reduced.

In an extensive system of this kind, the motor power involved in the operation of fans is sometimes as large as 1000 hp., or more and, if it happens that only one or two departments are running, an excessive amount of power is required for the handling of shavings. So far as the production of steam is concerned, it would be better to throw the shavings away but it is necessary to remove the shavings in some manner and, even though the system be inefficient, it may be cheaper to operate it than to tolerate the cost and inconvenience of hand trucking the shavings.

It is difficult to eliminate these power losses except by completely rebuilding the system, which is expensive. The condition may be of sufficient importance to justify re-arrangement of productive departments and the power and productive divisions must coöperate closely to see that the most advantageous solution is effected.

Installation Economy

Proverbially, the automobile industry is one of rapid change of production methods and schedules, which has its effect upon the class of construction that is desirable. If an electric welder, for instance, is to be left in one location possibly several years, it is probably justifiable to tear up the floor, if necessary, to provide concealed water connections and the electric wiring may be installed in pipe conduit. If there is probability of re-arrangement of apparatus, it is the belief of the writer that it is then unquestionably better from the standpoint of dollar efficiency to install open pipe work where it is not hazardous and to use Tyrex or Superservice cord from the nearest pull-box to the machine. This practice has been followed quite consistently for a number of years at Studebaker and, while it gives an inelegant appearance of the shop in places, great sums of money have been saved without appreciably increasing hazards or electric interruptions. This semi-permanent method of construction effects no reduction in the amount of power consumed but it is quite a factor in reducing expense incident to frequent changes.

Figure 3 shows a typical installation in which four motor switches and starters are mounted on a column, all being served with open Tyrex from the nearest junction box. The lines are clipped to the concrete to hold them in a workmanlike manner. Where motors are of more permanent nature, as in the tool room, the starting equipment is installed as shown by Fig. 4. The rack holding the safety switch and starter is a standardized affair made of 1½-in. angles for vertical members, to which are bolted flat steel cross members, which can be spotted at any desired location to hold the particular make or class of starter or switch to be installed. In case the motor should be changed, it is customary to leave the starter rack and service box intact for future use. These racks, being standard, can be made at odd times by the maintenance men and so have several available at all times.

Production line operation requires that machines be placed quite close together, which presents somewhat of a problem in the location of motor starting apparatus, if any attempt is made to keep it on the machine floor level. The practice which a number of plants are using and which is standard at Studebaker is to have an elevated platform, see headpiece, located above the countershaft suspension members, on which is located a group of safety switches and starters; the push button control for these is carried to convenient points near the machines. Energy is carried at 2300 volts to transformer substations, located at favorable points for centers of distribution, and from these transfer rooms standardized 500,000-cir. mil. circuits are carried in pipe conduit to the starting switch balconies.

Distribution from this point is decided from the considerations given above. If a machine seems permanent and time is available, the line from starter to motor is run in conduit; otherwise open construction is used, being careful to make it appear as workmanlike as possible by running parallel with building lines, making all drops vertical and taking out slack as much as possible.

Lamp Breakage

Considerable loss in the maintenance of equipment is incurred by the breakage of mazda and Cooper-Hewitt lights. In order to minimize this, an accurate record is kept of the location in which all Cooper-Hewitt tubes are broken and each month a report is sent out indicating where the breakage occurred. This has effected quite a decrease in the breakage of tubes because the system places the responsibility on the department in which the damage occurred.

A somewhat similar scheme is used to reduce the breakage of mazda lamps. The number of mazda lamps connected in each department is tabulated and the approximate number of burning hours shown along with it. Then each month lamps required by various departments are charged to them and at the end of the period it is possible to show, by comparing the number of lamps connected with the burning hours, how many lamps should have been required, were none broken or stolen. If the number actually used is in excess of this, it is called to the attention of the department foreman responsible. This, too, has resulted in a considerable decrease in the number of mazda lamps required.

Dirt Is Bad for Motors

Iron dust, which is likely to occur in cylinder block departments and others where gray iron is being machined is always sure to result in motor failures, unless definite precautions are taken to prevent them. The

cost of rewinding an induction motor is more than half the cost of a new motor, as a rule, so that rewinding must be reduced to a minimum. In order to accomplish this reduction, a careful and searching analysis was made of the direct and indirect causes of motor failures, —whether a tight belt, short, ground, or what not. In every case, the investigation was carried to the point of determining what definite steps should be taken for that particular motor to prevent a recurrence.

This investigation disclosed the following causes of motor failures in the order of their frequency of occurrence: 1. Dirt in windings or bearings; 2. Tight belts; 3. Dull tools and over-fusing.

As a result of the investigation, motors exposed to a dirt-laden atmosphere have had sheet metal covers provided, wherever possible. The enclosed motor is, of course, the answer to a situation of this kind, but from the standpoint of dollar efficiency cannot be used indiscriminately, so long as the open motor already in use is satisfactory in other respects.

In testing out new equipment, frequently fuses are blown and, in order to prevent a recurrence, the electrician will merely increase the size of the fuse or step up the setting of the breaker relay. This is sloppy practice and should never be tolerated, because it leads to motor failure in the end. Recognizing this fact, a considerable study of motor loads has been made to determine the maximum size of fuse which each motor should take. If the fuse blows too frequently, a graphic chart is taken from the motor to find the characteristics of the load producing the trouble and, if the motor is too small, a larger one is provided. Often it happens that the cause is a dull tool, or some unusual starting condition which can and should be promptly eliminated. These methods have reduced motor failures from thirty per month to five per month, on a total installation of 5400 motors.

Dirt in some form or other is one of the greatest factors in increasing plant engineers' maintenance costs and the matter of motor failures is no exception.

Allotment of Expense

In order to ascertain how the complexion of maintenance work may be changing in the plant from month to month, daily reports of every job performed by every maintenance man are made and, at the end of selected periods, these reports are tabulated to show whether some one phase of maintenance is becoming too heavy, or some phase which should receive attention is being neglected. The table shows the results of such an analysis of the entire activities of the electrical department for Studebaker corporation for the period one month. It does not follow that all plants should have the same distribution as shown here, even on the assumption that this is the best distribution possible for this plant, because, in some industries such as production of foodstuffs, cleanliness is of a different order from that possible or desirable in a metal working plant, so that the relative attention which must be devoted to the different items will be changed. But it is desirable, we believe, that any industry should make such an analysis because it will almost inevitably disclose some trouble which was hitherto unknown.

MAINTENANCE DISTRIBUTION TO BUILDINGS AND DEPARTMENTS

	Offices	Offices, Storage, Dies, Machine Repair, and Receiving	Wood Shops Frame Assembly Trimming	Body Assembly Salvage	Stamping, Stores, Pattern and Wood Shops	Body Assembly Car Storage Service School	Service Mech. Kilns Body Stamping P.A. Assembly	Forge Shop Foreign Shipping	Motor Building Co-operative Oil Stores	Tools Dies Gears	Final Assembly Misc. Parts	Stamping	Final Assembly Misc. Parts Shipping	Foundry	Spring Shop Small Forgings	Engineering & Offices	TOTAL	% OF TOTAL
BUILDING NO.	Adms. Bldg	1-1a-10A-10B 11-12-13-14 20-25-26-28 28A-29-30	3-4-5-6-7 71-8-9	200-24 24B-45-64	31-32-33-34 35-36-37-38 39-41-44-46	48-48A 47-47A	60-67-69 69A-68-68	71 - 93	71-94-95	78	79	80	82 - 83	85	86	92	TOTAL	% OF TOTAL
	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.
New Work	16.25					19.00		27.25	35.00	6.75	4.50		2.00				110.75	2.9
Changes	13.00	113.00	12.00	34.00	27.75	31.00	16.00	4.50	10.25	24.00	3.50		1.00	3.00	5.00		298.00	7.8
Lighting Circuits	8.50	21.00	1.50		3.25		1.50	.25			2.00			.50			38.50	1.1
Transf. & Busses											8.00			.50			8.50	.2
Time Clock Eqpt.	2.00	4.00	8.00	13.00	7.00	5.00	2.00	.50									41.50	1.1
Low Tension Circuits	29.75		2.00	.50	2.00	1.00	.75	.50	.50	2.50	2.25		7.00	3.00			51.75	1.3
Main Feeder Cir.& Swch					1.00									1.00			2.00	.1
Motor Control & Fuses	1.75	4.25	12.50	28.25	23.25	.50	15.00	15.00	51.50	30.24	14.00	9.00	20.50	122.50	12.75		361.00	9.4
Motor Cleaning	.50		11.00	1.75	16.00		8.00	1.75	17.00		1.00		1.50	21.00			79.50	2.1
Motor Oiling	4.75	61.00	58.25	55.50	111.00		93.50	26.00	89.50	92.50	83.50	29.00	26.50	136.00	13.50		880.50	23.0
Motor Repair	18.00	17.75	16.75	5.00	43.25		6.00	16.00	71.75	10.25	17.00	17.50	20.00	46.00	9.00		314.25	8.2
Motor Circuits	1.50		.50	3.00	4.25			3.75	1.50	9.00		11.75	1.50	11.25			48.00	1.3
Cooper-Hewitt Lamps			45.75	9.50			5.75	1.00	43.25	28.25	36.50	3.25	8.75	12.50			194.50	5.1
Mazda Lamps	12.25	10.25	6.25	35.25	4.00	.50	9.25	4.75	6.75	5.00	20.25		27.25	27.25	3.00	.50	172.50	4.5
Lighting Swtch & Fuses	2.25	12.50	10.00	22.25	6.50	.50	12.75		20.25	10.25	4.75	7.50	5.25	32.25			147.00	3.8
Elevators (Mechanical)	2.75									30.00	6.50		5.50	2.50	1.00		48.25	1.3
Elevator Motors	.50									8.50				1.50			10.50	.3
Elevator Controls	15.25	2.75	1.25	.50	4.50	2.25	11.75			8.00	6.50		6.00	26.00			84.75	2.2
Crane & Hoists (Mech)		2.00					7.00	18.00	32.00	18.00	21.50	1.75	8.00	65.50			173.75	4.5
Crane & Hoists (Motors)		1.50						24.50	8.50	1.00	7.00	22.50	1.00	8.50			74.50	1.9
Crane & Hoists(Control)		5.75					12.00	20.50	32.75	13.50	17.50		10.50	61.25	4.75		178.50	4.7
Generators	4.00			.50	.50						1.00			.50			6.50	.2
Electric Tools		5.00	2.25	64.75	5.75		10.00	2.00	50.00	27.00	36.50		29.00	1.00	3.00	1.50	237.75	6.2
Extension Cords	1.00	2.00	1.00	33.25	14.50		4.75	1.00	1.00	2.00	.50		5.25	7.25			73.50	1.9
Welders		1.50	13.50	85.00	10.00		16.75	3.00	1.50		11.50	12.50		1.50	3.50		160.25	4.2
Load checking & Testing	1.50														1.50		1.50	-
Heating Devices									10.75						14.50		25.25	.7
TOTAL	135.50	264.25	156.75	428.25	294.00	59.75	232.75	170.25	483.75	326.75	305.75	114.75	186.50	592.25	70.00	2.00	3823.25	100.0

Calculating Steam Pipe Sizes and Pressure Losses

ALLOWABLE PRESSURE DROP IS USUALLY THE DETERMINING FACTOR BUT IF NOISE AND WATER HAMMER ARE TO BE AVOIDED VELOCITIES MUST BE KEPT WITHIN CERTAIN LIMITS

CAPACITIES of steam pipe lines depend upon three factors: the velocity of the steam, the specific volume of the steam and the diameter of the pipe. For a given set of conditions, the flow can be calculated from the equation

$$W = \frac{0.327\ d^2\ v}{V}$$

Where W = steam flow in lb. per min.
d = inside pipe diameter.
v = velocity in ft. per min.
V = specific volume (from steam tables) in cu. ft. per lb.

It is evident that the pipe diameter necessary to transmit a given quantity of steam is a function of the

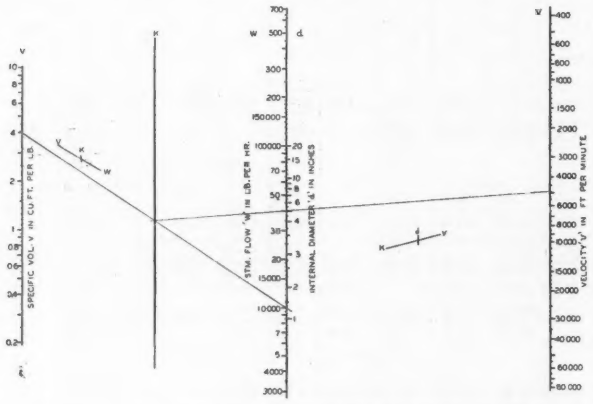


FIG. 1. CHART FOR DETERMINING VELOCITIES

velocity allowable or advisable under the existing conditions. This velocity will depend upon local conditions, steam quality, steam pressure and the pressure drop or friction loss which can be allowed and can be determined from the chart, Fig. 1.

Velocities may range from 4000 to 6000 ft. per min. for low-pressure saturated steam lines; 6000 to 8000 ft. per min. for moderate pressure saturated steam lines for reciprocating engines and general heating lines; 10,000 to 15,000 ft. per min. for moderate and high-pressure superheated steam turbine leads to as high as 50,000 to 75,000 ft. per min. for district steam heating feeder lines to outlying distribution centers.

CONDITIONS INFLUENCE VELOCITY

For building heating systems velocities must be kept down because of noise while with reciprocating engines and large steam pumps velocities must be kept low because of the pulsating effect and tendency toward vibration. Wet steam aggravates these conditions and may cause dangerous water hammer. This is especially true in long lines with many bends and fittings which make the line difficult to drain.

For industrial heating, process and drying work, higher velocities can be used. Often the pressure has to be reduced before the steam is used and a high pressure drop in the line is desirable as it reduces the

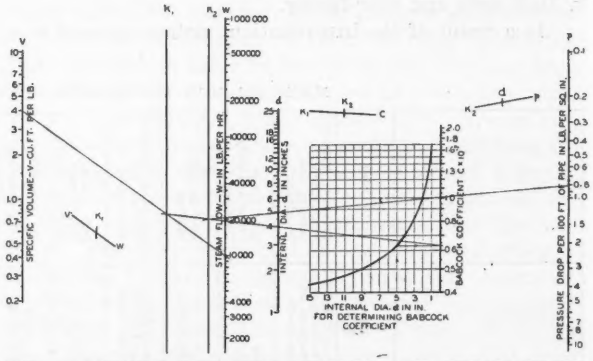

SPECIFIC VOLUME-V-CU.FT. PER LB.
STEAM FLOW-W-IN LB.PER HR.
INTERNAL DIA. d IN INCHES
BABCOCK COEFFICIENT C=10
INTERNAL DIA. d IN IN. FOR DETERMINING BABCOCK COEFFICIENT
PRESSURE DROP PER 100 FT. OF PIPE IN LB. PER SQ. IN.

FIG. 2. CHART FOR THE SOLUTION OF STEAM FLOW PROBLEMS USING THE BABCOCK COEFFICIENT

work of the pressure regulating valve. It must be remembered, however, that if the steam is of low quality where the water hammer must be avoided or the steam is exhausted from prime movers where the back pressure is important, velocities must be held down to the conservative values mentioned earlier.

For turbine leads, the velocity can be increased considerably because the steam is invariably superheated,

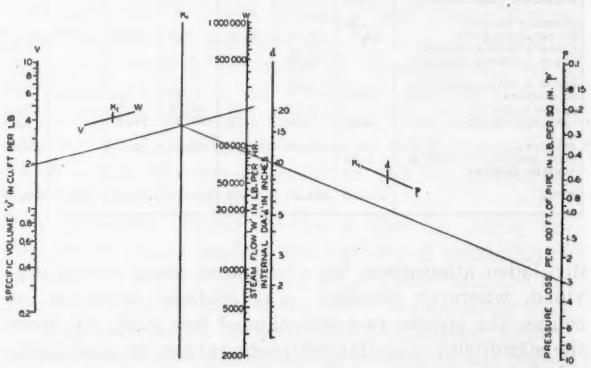

SPECIFIC VOLUME 'V' IN CU.FT PER LB
STEAM FLOW 'W' IN LB.PER HR.
INTERNAL DIA. 'd' IN INCHES
PRESSURE LOSS PER 100 FT. OF PIPE IN LB. PER SQ. IN. 'P'

FIG. 3. CHART FOR THE SOLUTION OF STEAM FLOW PROBLEMS USING THE FRITZSCHE FORMULA

there is no pulsating effect as in engine practice and the lines are usually short and direct. Extremely conservative practice for large sizes places 10,000 ft. per min. as the lower limit, ranging up to a maximum of about 15,000 ft. per min. for normal or 20,000 ft. per min. for emergency service. Velocities in small lines must, however, be kept down to a value of around 800 to 1000 ft. per min. per inch of inside pipe diameter, the lower value to be used with the small sizes. As the pipe size increases the value per inch of diameter can gradually be increased to 1000 ft. per min. for sizes of 12 in. and

larger, up to the maximum point of 15,000 ft. per min. regardless of size.

Pressure Loss Is Deciding Factor

No general rules can be followed in actual design, however, because of variable load conditions. High velocities mean smaller lines, reducing the first cost and radiation losses. At the same time, it may be desirable to use a larger line than actually necessary in order to standardize sizes and reduce the necessary stock of tools, spare valves and fittings. Again space requirements may dictate a size much smaller than would normally be used.

In general power plant practice, the pressure drop is the determining factor. There is, of course, a definite

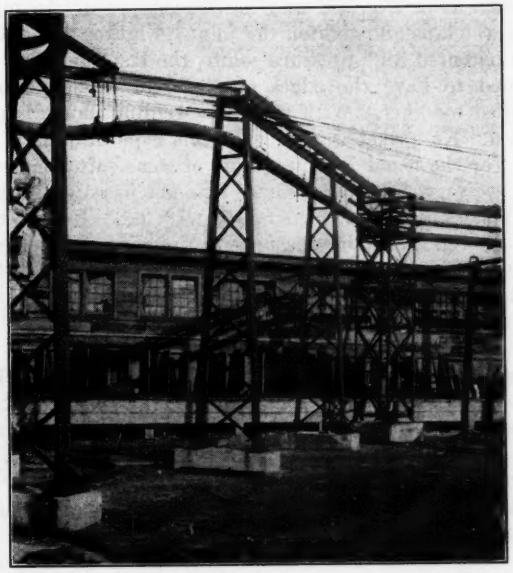


FIG. 4. A SUBSTANTIAL AND FLEXIBLE ARRANGEMENT FOR AN OUTDOOR STEAM LINE

relation between velocity and pressure loss, but it is not always readily calculated in spite of the great amount of experimental work which has been done. Velocity, on the other hand, is easily calculated and this no doubt accounts for its wide use in design calculations regardless of the fact that the pressure drop is in the end the deciding factor.

In spite of the experimental work mentioned, the exact relation between velocity and pressure drop is not known. One formula widely used for calculating the flow and commonly known as the Unwin or Babcock formula is:

$$P = \frac{C\,L\,V\,W^2}{d^5} \qquad (2)$$

Where P = pressure drop in lb. per sq. in.
C = frictional coefficient
W = steam flow in lb. per hr.
L = length of pipe in ft.
V = specific volume in cu. ft. per lb. (average of initial and final pressure)
d = internal diameter of pipe in in.

In fact, this is a general form of all flow pipe formula and a graphical solution is given by Fig. 2 where L = 100 and p = the pressure loss for 100 ft. of straight or equivalent length of pipe.

Various values have been given for the frictional coefficient C which varies with the diameter of the pipe, the velocity of the passing steam and, recent data indicate, with the specific volume of the steam as well. Perhaps the most widely used for steam is the Babcock coefficient

$$C = \frac{0.3628}{10^7} + \frac{(1 + 3.6)}{d} \qquad (3)$$

which can also be determined graphically from Fig. 2.

For long lines, moderate pressures and saturated steam this gives approximately correct results but for higher pressures and larger diameters the calculated pressure loss is higher than is actually the case. Early experience at Hell Gate with moderate pressure, superheated steam showed that the actual losses were only about a half of that calculated with the Babcock coefficient. Recent experience at Lakeside with small diameter superheater tubes confirms this as the actual drop is only 18 instead of 35 lb. as calculated from the Babcock formula.

For high velocities, higher pressures, superheated steam and steam lines of 8 to 10 in. and larger, Fritzsche's Coefficient which varies as the 2/7 power of the diameter and inversely as the 1/7 power of the velocity gives better results. Using the same symbols as before, the Fritzsche formula can be written.

$$P = \frac{2.1082\,L\,V\,W^{1.852}}{10^7 \times d^{4.973}}$$

Fractional exponents make this difficult to solve and the chart, Fig. 3, has been constructed to facilitate calculations. In this chart, L = 100 and p = the pressure drop for each 100 ft. of straight or equivalent length of pipe.

Building Flexibility Into the Steam Line

Fittings, Expansion Joints, Bends, Anchors and Supports Must All Be Coördinated

COMPLETION of tentative or accepted standards and specifications for piping and fittings has done much to simplify the piping and fittings details for the engineer and leave more time to be devoted to design of the piping system itself.

Welding is being used to a greater extent than ever before and offers advantages which cannot be discounted. Its use for air, water and gas lines especially for moderate temperatures and pressures up to 75 to 100 lb. is relatively common. It has also been used to a considerable extent for steam lines up to 150 to 200 lb. but state, city and insurance codes should be examined carefully before any considerable amount of work is planned.

Welding saves the cost of companion flanges and bolts, lowers the cost of erection, decreases insulation costs and eliminates leaks. Saving possible is greater with large than with small sizes and disappears at about the 3 or 4-in. size where low cost screwed fittings are normally used. Construction of welded lines has been

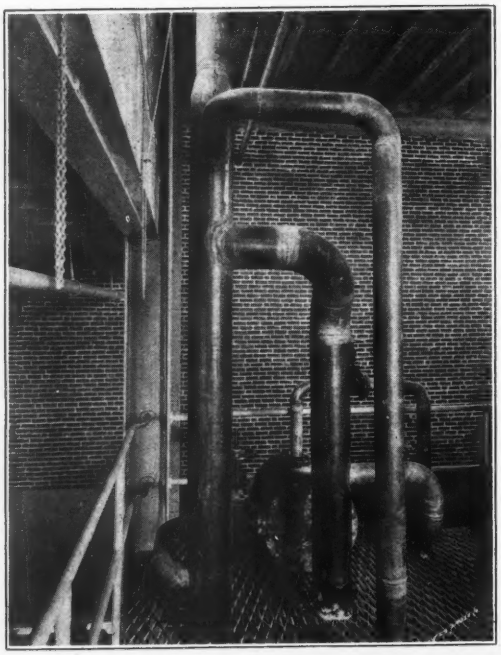


FIG. 1. MANUFACTURED BENDS AS USED IN WELDED LINES. NOTE AT THE TOP THE EASE WITH WHICH REDUCING FITTINGS CAN BE MADE

greatly facilitated by the introduction of ready-made elbows and bends of the type shown in Fig. 1. These come with the edges scarfed ready to butt weld in the line, making a joint somewhat like Fig. 2-A.

If welding is not used, flanged or screwed joints must be employed to join the pipe sections and make a fluid tight joint. Several types of flange joints are shown in Fig. 2-B, C D and E. With moderate pressures and small sizes, flanges are screwed on as in Fig. 2-B. For higher pressures, the end of the pipe is flared or Van

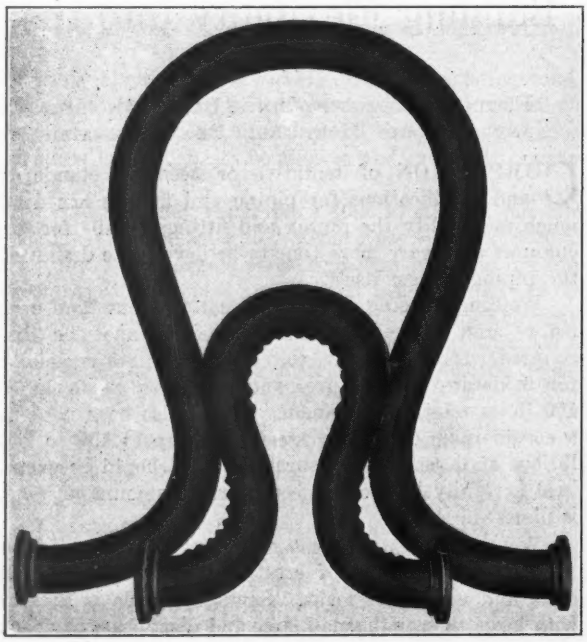


FIG. 1A. COMPARISON OF A PLAIN BEND AND CREASED BEND FOR THE SAME SPECIFICATION

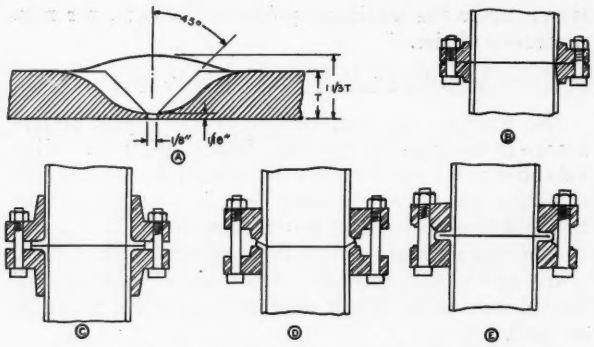


FIG. 2. A, TYPICAL BUTT WELD, B, C, D AND E, DIFFERENT TYPES OF FLANGED JOINTS

Stoned as in Fig. 2-C and the flanges are drawn up to grip the laps and tighten the joint. Figures 2-D and E are patented high-pressure joints, the last one being designed to have the edges of the Van Stoned flanges welded together. With fittings a welding flange is provided. No gasket is used with this type of joint.

For the usual joint, a gasket of some softer material is necessary, however, because it is not usually practical to make the flange faces absolutely flat. In order to insure tightness, the gasket pressure must be considerably higher than the steam pressure in the pipe and in order to do this without excessive bolt tension, the gasket area is usually smaller than the flange area.

Gaskets must be made of some material that is not affected by the steam at its working temperature. Red rubber is satisfactory for pressure up to a little above atmosphere, while metal or composition gaskets (usually of asbestos) are used for higher pressures and temperatures. For metal gaskets copper is satisfactory up to 300 deg. F. but above this iron, steel or monel should be used.

Bolts should receive considerable attention especially for the higher temperatures and pressures. For moderate pressure, carbon-steel bolts are satisfactory, but for high pressure, alloy steel studs with nuts on both ends should be used. Physical properties and tests of such materials are well covered in the standard specifications. The coefficient of expansion is an important item to be considered. If it is lower in the bolt than in the flange, the bolt will be overstressed, while if higher the joint will not be tight. Furthermore they should

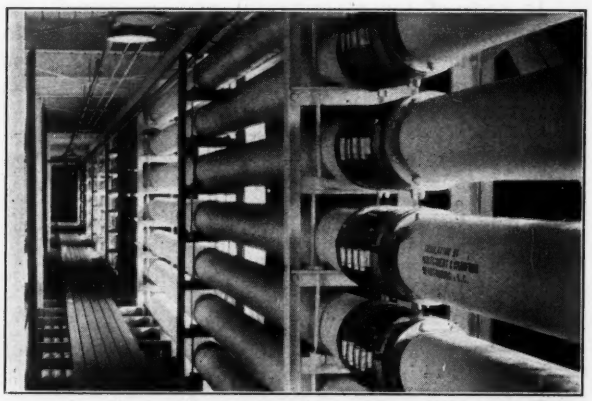


FIG. 3. EXPANSION JOINTS IN A WELL DESIGNED TUNNEL

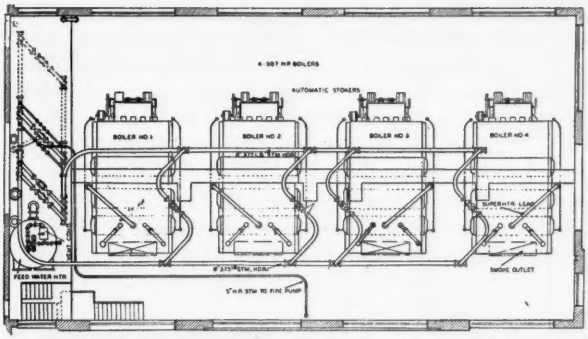


FIG. 4. FLEXIBILITY BUILT INTO BOILER ROOM PIPING

expand at about the same rate. Trouble has been experienced from bolts expanding faster than the flange causing leaks which are open during the warming up period but close as the flanges expand and take up the slack.

Expansion of the pipe itself is taken care of in several different ways. For low and moderate pressures,

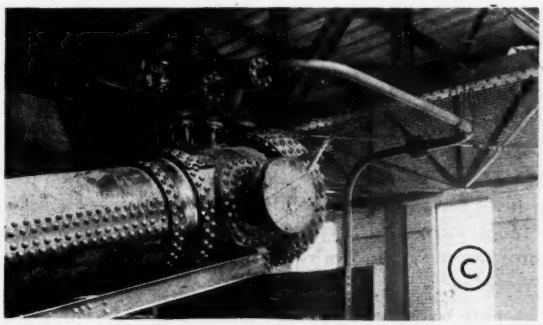


FIG. 5. EXPANSION IN 1400-LB. STEAM LINE TAKEN CARE OF BY FLEXIBLE DESIGN

expansion joints, of which there are a number of types, are used. For high-pressure steam lines, however, it is usual to utilize the inherent flexibility of the pipe by inserting bends, loops, turns and offsets in the line. Expansion loops are common for this service. A recent development of this is the creased bends corrugated on the inside radius and reducing by a considerable amount the space required for the older form of plain bend.

Examples of flexibility built into the piping without utilizing special expansion bends are shown in Figs. 4

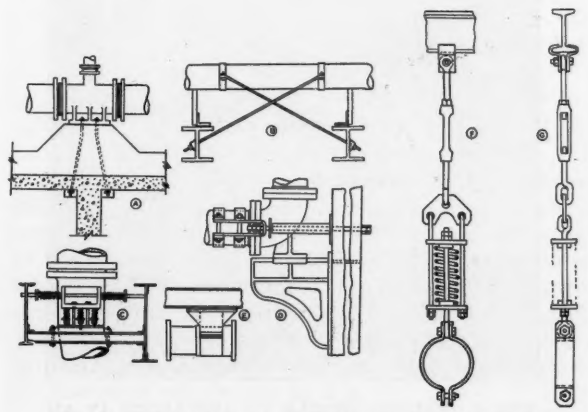


FIG. 6. SEVERAL PRACTICAL PIPE ANCHORS

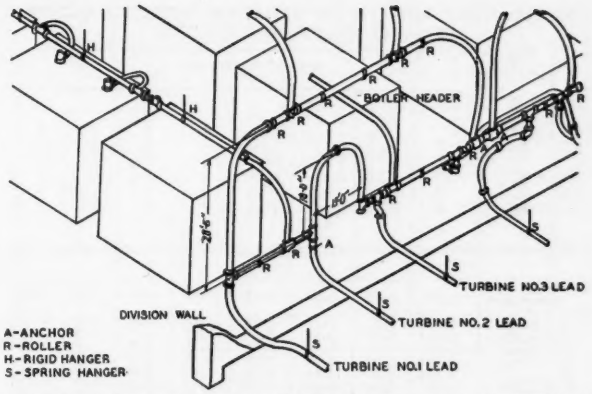


FIG. 7. ANCHORS AND SUPPORTS AS USED IN A TYPICAL STATION

and 5. The former is a recent industrial plant where flexibility of the boiler leads is obtained by the S design and flexibility between the headers by the 45-deg. angle cross connections. In Fig. 5 the small pipe in the foreground is the 1400-lb. steam connection to a steam reheater, flexibility being obtained by the double bend.

In order to insure expansion strains being thrown upon the expansion member, the pipe must be securely anchored at definite intervals and properly supported. Details of several anchor and a spring support designs which have been employed with satisfactory results are shown in Fig. 6. Sometimes base fittings can be used to advantage. The balance of the pipe must be free to move. This is sometimes accomplished by resting the pipe on rollers, or by suspending it on flexible piping supports such as Fig. 6-F. The arrangement of anchors, rollers and hanger in a typical, well designed power plant is shown in Fig. 7.

Valves and Fittings in the Piping System

FRICTION LOSS THROUGH VALVES AND FITTINGS
REDUCING VALVE LAYOUT AND SERVICE OUTLETS

FRICTION OR RESISTANCE to flow plays a large part in the selection of valves and fittings for various locations. Gate valves, because of the direct flow, offer but a fraction of the flow resistance of globe valves and should be used in all steam lines where the valve will always be wide open or tight closed. Globe valves, on the other hand, are better for locations where the flow must be controlled as they not only give better regulation but the valve and seat can be more easily removed for repair.

When calculating pressure drops in steam lines, the resistance of valves and fittings is commonly expressed as an equivalent length of straight pipe. According to Foster's formula, this equivalent length for steam flow is:

$$L = 43.7\ r\ d^{1.2}$$

Where L = equivalent length of straight pipe in ft.
d = diameter in ft.
r = resistance factor (top line of the table)

Values calculated for various fittings by means of this formula are given in the accompanying table.

EQUIVALENT LENGTH OF STRAIGHT PIPE TO ALLOW FOR FRICTION OF FITTINGS

Nominal Pipe Size, in.	Actual Inside Diameter, in.	Form of Resistance: Gate Valve	Long Sweep Elbow or on Run of Standard Tee	Medium-Sweep Elbow or on Run or Tee reduced in Size ¼	Standard Elbow or on Run or Tee Reduced in Size ½	Angle Valve	Close Return Bend	Tee through Side Outlet	Globe Valve
Factor of Resistance		0.25	0.33	0.42	0.67	0.90	1.00	1.33	2.00
¼	0.622	0.031	0.41	0.52	0.84	1.12	1.25	1.66	2.50
⅜	0.824	0.044	0.57	0.73	1.17	1.57	1.75	2.33	3.50
½	1.049	0.057	0.77	0.98	1.57	2.11	2.34	3.11	4.68
¾	1.380	0.082	1.07	1.37	2.19	2.94	3.27	4.35	6.54
1	1.610	0.098	1.29	1.64	2.63	3.52	3.92	5.21	7.84
1¼	2.067	1.32	1.74	2.23	3.55	4.77	5.30	7.05	10.60
1½	2.469	1.64	2.16	2.75	4.39	5.91	6.56	8.71	13.12
2	3.068	2.13	2.81	3.59	5.72	7.69	8.54	11.40	17.08
2½	3.548	2.53	3.34	4.26	6.80	9.10	10.13	13.50	20.26
3	4.026	2.96	3.90	4.97	7.94	10.65	11.84	15.75	23.68
3½	4.506	3.27	4.45	5.66	9.05	12.14	13.50	17.95	27.00
4	5.047	3.88	5.11	6.52	10.40	13.95	15.51	20.60	31.02
5	6.068	4.81	6.35	8.09	12.90	17.35	19.27	25.60	38.54
6	7.023	5.75	7.59	9.66	15.40	20.70	23.02	30.60	46.08
8	7.981	6.70	8.85	11.30	17.90	24.10	26.80	35.60	53.60
10	10.02	8.75	11.54	14.70	23.40	31.50	35.00	46.60	70.00
12	12.09	10.90	14.40	18.35	29.30	39.30	43.70	58.10	87.40

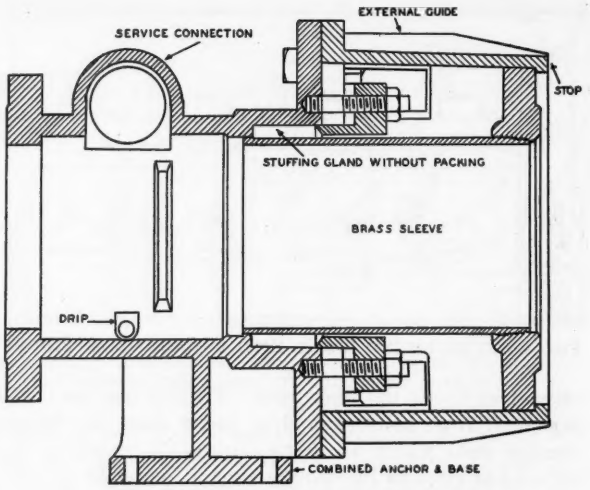


FIG. 3. SLIP JOINT WITH SERVICE OUTLET INCORPORATED

Brass and bronze are the commonly used materials for moderate pressures and temperatures, cast iron for large sizes up to 250 lb. and 400 deg. F. and cast steel or alloy steel for higher temperatures. Forged steel and monel metal are also used for severe service in small sizes. Valve discs and seats for high-pressure service are extremely important; monel metal, nickel and chromium, iron alloys are being used for this service.

Pressure reducing valves are also a matter of considerable importance and should be selected and installed with care. Many types are available to meet all conditions of service but any type is subjected to continuous throttling action which tends to wear or cut. This action is aggravated by the general tendency to select a valve which is too large for the service intended. Instead of the valve being nearly open in normal service, it is nearly closed and wiredrawing results.

Valves should be selected on the basis of a reasonable velocity of say 6000 ft. per min. on the inlet side. If considerable seasonal variation is expected, it is well to use two valves of different capacities in parallel so that the one best suited to the load can be used. If the reduction in pressure is considerable, two valves in series are frequently used.

In order to protect the low-pressure system against accidents or leaky valves while no steam is being used, the low-pressure side should be equipped with a safety or relief valve. A bypass should also be provided to insure service when the reducing valve is being repaired or reseated.

A gate valve on each side of the reducing valve with a single valve in the bypass is sufficient but an arrangement similar to Fig. 1 with two gate and one globe valve in the bypass is preferable. The gate valves are used

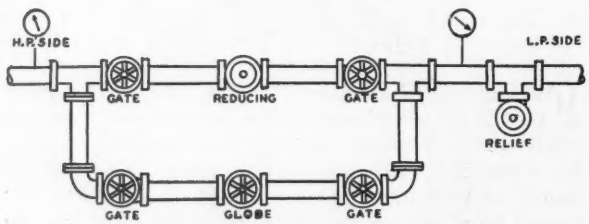


FIG. 1. RECOMMENDED REDUCING VALVE INSTALLATION WITH BYPASS, GAGES AND RELIEF VALVE

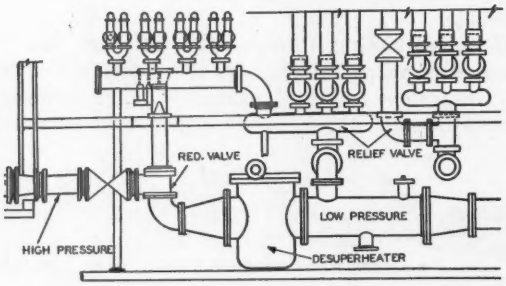


FIG. 2. HIGH-PRESSURE REDUCING VALVE AND DESUPERHEATER ARRANGEMENT IN AN INDUSTRIAL PLANT

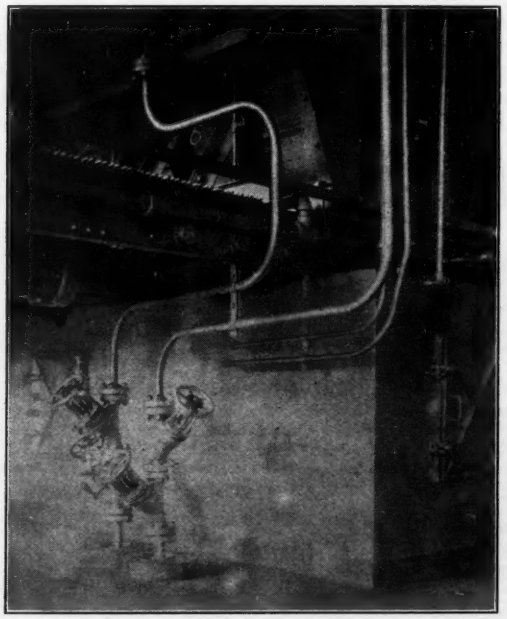


FIG. 4. VALVES SHOULD BE INSTALLED IN AN ACCESSIBLE LOCATION

to shut off the flow completely, the globe valve for hand regulation when necessary. When reducing high-pressure, high-temperature steam in emergencies as for instance, around a high pressure turbine element, desuperheaters should be provided. Such an installation in an industrial plant is shown by Fig. 2.

Outlets and service connections should be conveniently located and are usually made with tie or cross fittings, although in low-pressure distribution systems a service outlet is frequently incorporated, shown by the expansion joint in Fig. 3.

Calculating Heat Losses from Insulated Lines

Effect of Air Velocities and Curvature of Pipe Surfaces Must Be Taken Into Account

STEAM PIPES are insulated primarily to prevent losses and save fuel. This is not the only function of insulation, however, as it also minimizes temperature drops in superheated steam lines, minimizes condensation in saturated steam lines, decreases temperature strain on pipe and fittings and improves working conditions.

Heat losses from bare surfaces are increased greatly by moving air and at a surface temperature of 500 deg. F. the heat loss with an air velocity of about 1160 f.p.m. is double the loss in still air. As the surface temperature drops, the effect of the velocity increases and at a surface temperature of 200 deg. F. the still air heat loss is doubled by air velocity of but 750 f.p.m.

Rate of heat transfer depends primarily upon the relative temperature of the hot surface and the surrounding air, the resistance of the insulation and surface resistance. In the case of flat surfaces, it can be calculated from the equation

$$H_f = \frac{T_1 - T_2}{\frac{X}{C} + \frac{1}{K}}$$

Where

H_f = flat surface heat flow, B.t.u. per sq. ft. per hr.

T_1 = temperature of pipe, deg. F.

T_2 = temperature of air, deg. F.

X = thickness of insulation, in.

C = coefficient of thermal conductivity from flat surface, B.t.u. per sq. ft. per hr. per deg. F. per in. of thickness

K = surface resistance on heat transfer from the insulated surface to air in B.t.u. per sq. ft. per deg. F. per hr.

Conductivity is a property of the material and varies with the temperature. Values of a number of the more common insulating materials as collected and tabulated by Heilman are given in Fig. 1. Surface resistance is a large part of the total resistance to heat flow in good conductors but is not as important in the case of good insulators. Its value changes materially with air velocity and total heat flow and is given sufficiently accurate for insulation calculations by Fig. 2.

Except on flat surfaces, the internal resistance of the material does not vary directly as the thickness. With cylindrical surfaces, additional thickness increases the resistance to heat flow but also increases the areas of the path through which the heat must flow. In order to take account of this fact, both the radius of the pipe and the radius of the covering must be used to reconcile coefficients from flat surface tests with curved pipe surfaces. This relation is a logarithmic function of the two diameters. Based on the areas of the outside surface

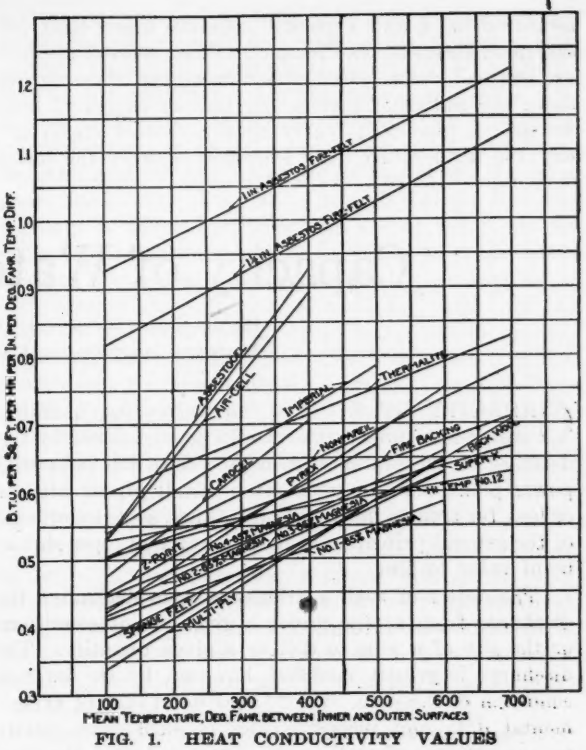


FIG. 1. HEAT CONDUCTIVITY VALUES

$$H_c = \frac{T_1 - T_2}{\frac{r_c \log_e (r_c \div r_p)}{C} + \frac{1}{K}} \qquad (2)$$

Where H_c = heat flow per hr. per sq. ft. of outside surface

r_c = outside radius of pipe covering

r_p = outside radius of pipe

Referred back to the pipe surface

$$H_p = \frac{r_c}{r_p} H_c \qquad (3)$$

Where H_p = heat flow per hr. per sq. ft. of pipe surface

Heat losses from lines carrying superheated steam

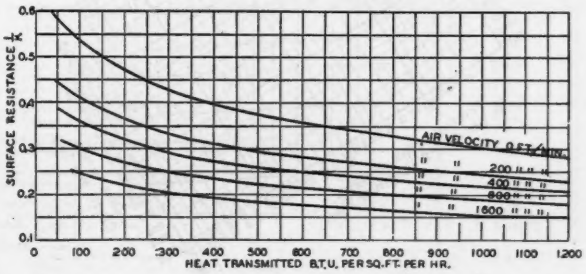


FIG. 2. SURFACE RESISTANCES AT DIFFERENT AIR VELOCITIES

measured on a unit capacity basis are lower than for saturated steam for two reasons: First, specific volumes are less and steam velocities can be higher, thus cutting down the radiating surface per unit of capacity; and, second, as pipe walls carrying superheated steam are dry, the temperature drop is greater between the steam and wall. This temperature gradient is in effect another insulating layer. With saturated steam, the walls are wet and at materially the same temperatures as the steam, improving the heat transfer and giving a higher pipe radiating temperature for the same steam temperature.

Capacity of Water Piping Systems

PRINCIPLES GOVERNING FLOW OF WATER IN PIPES, FACTORS THAT CAUSE LOSS OF HEAD, WATER HAMMER

CAPACITY OF PIPING and valves for handling water is a subject that should be considered by the designer of the piping system but, since the industrial power plant engineer must often install piping himself or look for trouble in existing pipe lines, some knowledge of the general principles of flow of water in pipes should be of value to him.

The object of such a discussion is to determine the discharge from a pipe under a given set of conditions or the size of a pipe to deliver a given quantity. The discharge is greatly modified, however, by the interior condition of the pipe. Partly because of lack of experimental data and inconsistencies in such data, partly because of imperfect theoretical knowledge of the laws of flow, existing experimental data, taken with the greatest care often give conflicting results and in practice, the engineer may also obtain conflicting results. Fortunately in most designs of piping systems, errors of five or ten per cent are not unduly serious, although they should be on the side of safety and of course should be avoided if possible.

RELATION OF QUANTITY TO HEAD

Quantity of water discharged from a pipe depends upon the head. If this discharge occurs freely into the air, this head is the difference in level between surface of water in the reservoir and the center of the discharge end of the pipe; if the lower end of the pipe is submerged, the head is the difference of the two levels. For a given diameter, the discharge depends also upon length of pipe, character of interior surface, number of valves or other partial obstructions and number and sharpness of bends.

Instead of being an actual distance between two levels, the head may be caused by pressure, in which case head is calculated as a vertical distance correspond-

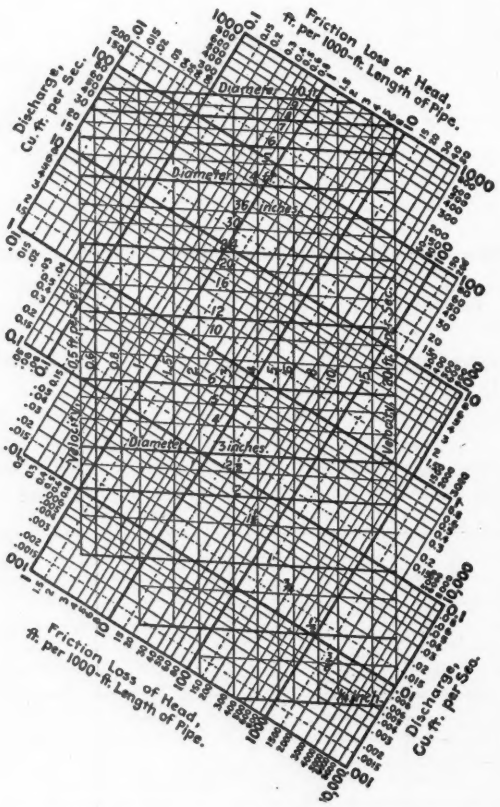

Friction Loss of Head, ft. per 1000-ft. Length of Pipe.
Discharge, Cu. ft. per Sec.
Diameter, Inches
Velocity, Ft. per Sec.
Friction Loss of Head, ft. per 1000-ft. Length of Pipe.
Discharge, Cu. ft. per Sec.

FIG. 1. PIPE-FLOW DIAGRAM FOR CAST-IRON AND WROUGHT-IRON PIPE IN FAIR CONDITION

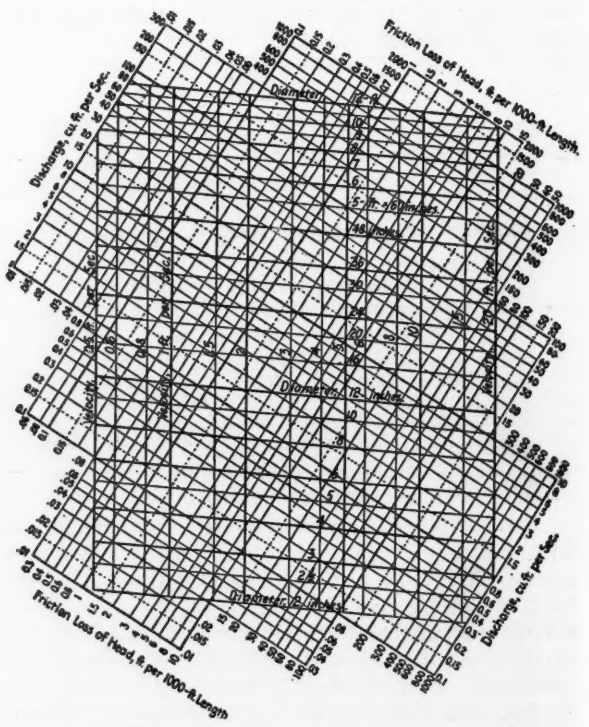

Friction Loss of Head, ft. per 1000-ft. Length.
Discharge, cu. ft. per Sec.
Diameter, Inches
Velocity, Ft. per Sec.
Friction Loss of Head, ft. per 1000-ft. Length
Discharge, cu. ft. per Sec.

FIG. 2. PIPE-FLOW DIAGRAM FOR RIVETED PIPES AND ROUGH PIPES; FOR EXAMPLE CAST AND WROUGHT IRON PIPE AFTER 10 YR. SERVICE

TABLE I. EQUIVALENT RESISTANCE OF SCREWED FITTINGS; LENGTH OF PIPE IN FEET

Nominal pipe size inches	Actual inside diameter inches	Gate Valve	Long radius ell or on run of standard tee	Medium radius ell or on run of tee reduced in size 25 per cent	Standard ell or on run of tee reduced in size 50 per cent	Angle Valve	Close return bend	Tee through side outlet	Globe Valve
Resistance ratio for type of fitting		0.25	0.33	0.42	0.67	0.90	1.00	1.33	2.00
Water and non-viscous liquids									
¼	0.622	0.53	0.44	0.56	0.89	0.89	1.4	1.8	2.7
⅜	0.824	0.42	0.83	0.75	1.3	1.7	1.9	2.5	3.8
1	1.049	0.44	0.84	1.1	1.7	2.3	2.5	3.4	5.1
1¼	1.380	0.90	1.2	1.5	2.4	3.2	3.6	4.8	7.2
1½	1.610	1.1	1.4	1.8	2.8	3.9	4.4	5.8	8.7
2	2.067	1.5	1.9	2.5	4.0	5.4	6.0	7.9	11.9
2½	2.469	1.9	2.5	3.1	5.0	6.7	7.5	9.9	14.9
3	3.068	2.5	3.3	4.1	6.7	8.9	9.9	13.1	19.7
4	4.026	3.4	4.5	5.9	9.2	12.4	13.7	18.3	27.5
5	5.047	4.6	6.0	7.7	12.0	16.2	17.9	24.0	36.0
6	6.065	5.7	7.6	9.6	15.5	20.6	22.9	30.4	45.8
8	7.981	8.1	10.7	13.6	21.7	29.2	32.4	43.1	64.8
10	10.02	10.7	14.1	17.9	28.7	38.5	42.8	56.9	85.6
12	12.000	12.5	17.6	22.7	36.2	48.5	54.0	71.8	108.0

[1] Computed by Foster's formulas. For steam $L_e = 43.7rd^{1.2}$. For water $L_e = 53.75rd^{1.25}$ L_e = equivalent length of straight pipe in feet; r = resistance factor; d = diameter of fitting in feet. For flanged fittings use three-fourths the resistance of screw fittings. A.S.M.E. Trans. Vol. 42,p.648,1920.

ing to the pressure, figuring one pound per square inch equal to 2.309 ft. or one foot head equal to 0.433 lb. per sq. in. pressure.

Velocity considered in a pipe is mean velocity, expressed in the formula $Q = AV$ in which Q is quantity discharged in cubic feet per second, A the area in square feet, V the mean velocity in feet per second.

Total Head

Total head, says National Pipe Standards, may be divided into five parts: H, the velocity head; H_e, loss of head at entrance; H_f, loss of head through friction; H_o, loss of head due to obstructions; H_b, loss of head due to bends.

Velocity head is the height through which a body must fall to acquire the velocity with which the water flows in the pipe or

$$H = V^2 \div 2g, \text{ where } g = 32.2$$

Loss of head at entrance is expressed by $H_e = K_1 (V^2 \div 2g)$ where K_1, a constant, has the following values: for inward projecting entrance, 0.78; sharp edged entrance, 0.50; slightly rounded entrance, 0.23; bell-mouthed entrance, 0.04.

Since quantity of flow, length of pipe and friction loss are interrelated it is necessary to consider all three in considering carrying capacity of pipes. Application of the common empirical equations for water flow is limited to water at usual atmospheric temperatures of say 32 to 100 deg. F. For higher temperatures, changes in density and viscosity have a bearing and for extremely accurate results are taken into account by some of the flow formulas.

Formulas for Flow of Water in Pipes

One of the most carefully worked out empirical formulas is that of Saph and Schoder, as given by the Piping Handbook and Marks' Mechanical Engineer's Handbook. It is based on careful experiments and the results agree closely with those obtained by other methods.

This formula is $H_f = 0.38 (V^{1.86} \div D^{1.25})$ where H_f is head lost in feet of water per 1000 ft. of pipe, V is velocity in feet per second, D is inside diameter of pipe in feet. The charts, Figs. 1 and 2 are based on this formula and various pipe handbooks also give tables of carrying capacity based on this and other formulas.

As the interior condition of the pipe is an important factor in the flow, Fig. 1, based on the above formula, is for cast iron and wrought iron pipe in fair interior condition. For rough or riveted pipes, Fig. 2 should be used, based on the formula $H_f = 0.5 (V^{1.95} \div D^{1.25})$.

"In attempting to compute the capacity of a pipe line or to figure probable loss in head after a pipe has reached a certain age, it is absolutely essential to know something about the water to be conveyed. In most cases, the quality of the water is such that the carrying capacity is affected little by the age of the pipe. In other cases, the water may be so soft as to cause tuberculation and consequent loss in carrying capacity or so turbid as to cause deposits of sand and mud with the same effect. Waters that cause tuberculation are the rare exception and outside of a few raw water conduits, muddy water is also unusual," says the Cast Iron Pipe Research Association. For that reason, it questions the correctness of applying a definite correction factor to flow formulas as the pipe increases in age.

Obstructions Cause Loss of Head

Loss of head in pipes due to bends, valves, fittings, or other partial obstructions should always be taken into account if satisfactory results are to be obtained. Table I gives equivalent resistance of screw fittings in length of pipe in feet for pipe of various diameters. Table II shows loss of head due to curves, elbows, meters and so on.

Care must be taken to prevent pipes from becoming air bound by air entrapped at high points of vertical curves in the line. The remedy for this is to provide cocks, valves or automatic float valves at the high points.

Water hammer is sometimes encountered in pipe lines and is dangerous, as it may cause rupture at some point. It occurs when a valve in a pipe is closed while water is flowing, retarding the velocity of water behind the valve and producing a dynamic pressure. When the valve is closed quickly, this pressure may be much greater than that due to static pressure. To guard against it, arrangements are made to prevent rapid closing of valves. Letting P_o represent static pressure at no flow; P_1 static pressure during flow; P maximum dynamic pressure due to water hammer in excess over the pressure P_o; V velocity in feet per second; L length of pipe back from valve in feet and T time of closing of valve in seconds, the formula

$$T = 0.027 [LV \div (P_o - P_1)]$$

gives the time for closing the valve in order that there may be no water hammer.

TABLE II. LOSS OF HEAD DUE TO CURVES, ELBOWS, METERS

Nature of Resistance	Loss of head as a decimal or multiple of $V^2/2g$ (Safe Ave. values)	Equivalent length of straight pipe expressed in pipe diameters
Square-edged entry. Upstream end of pipe flush with inside face of reservoir wall	0.50	20
Entry like Borda's mouthpiece (see Orifices)	1.00	40
Rounded entry or very large radius bends	0 to 0.05	Zero
90-deg. curves, smooth,* same inside diam. as pipe:		
Center-line radius = diam. of pipe	0.50	20
Center-line radius = 2 to 8 diams.	0.25	10
90-deg. elbows, common screw end, short turn (experiments on 3/8 to 6 in. ells)	0.75	30
Tees, common screw end, full size branch (experiments on 1- to 4-in. tees)	1.50	60
Square elbow (intersection of two cylinders)	1.25	50
Obtuse-angled elbows, deflection in pipe = a deg. (less than 90 deg.	$1.25 \times (a/90)^2$	$50 \times (a/90)^2$
Water meters**		
Disk, or wobble type	3.4 to 10	135 to 400
Rotary (disk of star or cog-wheel shape as piston)	10	400
Reciprocating piston (like a piston pump)	15	600
Turbine wheel type (double flow, balanced)	5 to 7.5	200 to 300

Controlling Flow of Water

CHANGING SPEED OF PUMPS AND USE OF SUITABLE VALVES IN SUCTION AND DISCHARGE LINES ARE MEANS OF REGULATING WATER FLOW

PUMPS used in industry for handling liquids fall into four general classifications: pistonless pumps, reciprocating pumps, rotary pumps, centrifugal pumps. Control of flow from pumps depends on the suction lift, discharge head volume and speed.

Pulsometers or pistonless steam-operated displacement pumps are built for suction lifts up to 26 ft., preferably 7 to 14 ft. and discharge heads up to 150 ft. Steam pressure must be about 50 per cent higher than the total water pressure. Water jet pumps used in mines, foundation work, drainage and so on are made in capacities up to 7000 g.p.m. driven by water entering under head of 10 to 2500 ft. Steam jet pumps or injectors, sometimes used for boiler feeding, may have capacities of 21 lb. water per pound of steam at 20 lb. gage to 10 lb. water per lb. steam at 100 lb. gage.

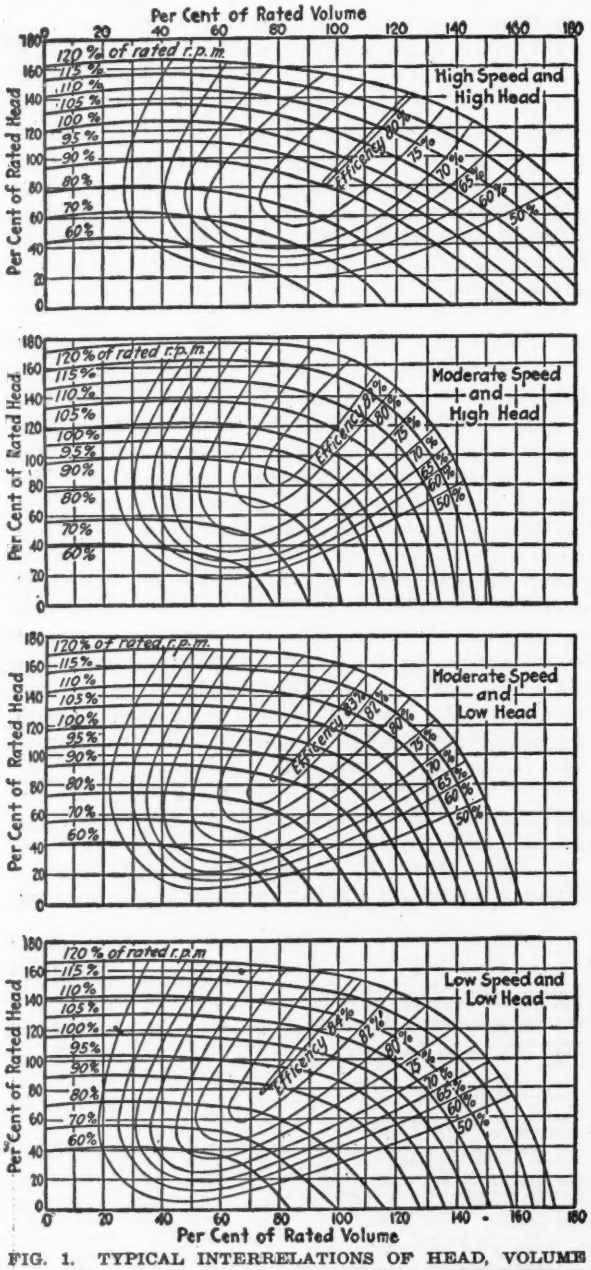


FIG. 1. TYPICAL INTERRELATIONS OF HEAD, VOLUME AND R.P.M. FOR GOOD COMMERCIAL CENTRIFUGAL PUMPS

USES OF INJECTORS

The ejector is designed to handle large quantities of gases, liquids or even solids against a pressure less than that of the actuating fluid, which may be steam water, or other high pressure vapor, gas or liquid. Ejectors are used for well pumps, bilge pumps, for lifting muddy, acid and alkaline liquid for air exhausters for priming centrifugal pumps and so on. They range in capacity as made by one manufacturer, from 220 g.p.h. at 20 lb. steam pressure to 1300 g.p.h. at 100 lb. pressure.

Air lifts often used for pumping water from deep wells have capacities, depending on type of well, submergence, diameter of air pipe and casing, and other factors.

Speed of pumps driven by oil engines is best regulated by a device that limits the amount of oil injected per stroke, rather than by the speed governor, the latter being kept for emergency speed control, according to the Worthington Pump Handbook. By use of suitable gearing the most favorable pump speeds can be obtained for high head service. Gasoline and kerosene engines are often used to drive centrifugal pumps, either by belt or direct connected. In some cases, as in water pumping plants, centrifugal pumps for auxiliary or station service are driven by small water wheels, taking their driving water from the main pump and discharging back to the suction. Water wheel driven pumps have been used in irrigation work, on evaporators in sugar and salt works, for mining work in case of flood conditions, on dredges and so on.

STEAM TURBINE DRIVEN PUMPS

Rating of steam turbines driving centrifugal pumps should always be on the maximum load, otherwise expected efficiency may not be obtained. On overloads, a steam turbine will simply reduce its speed to a point where power developed by the turbine will equal the power demand of the pump. The speed of the turbine can be altered by adjusting the governor, which can be equipped to operate by the discharge pressure of the pump, thus regulating the speed of the turbine automatically.

The most common and simplest driver for centrifugal pumps and for power displacement pumps is the electric motor. Worthington Pump Handbook gives the following general motor recommendation.

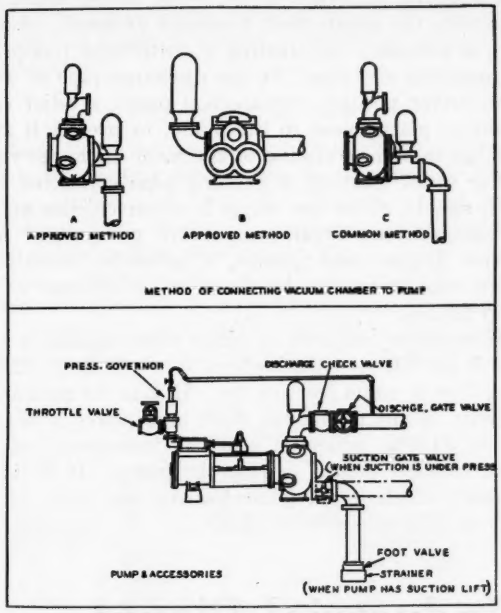


FIG. 4. CONNECTIONS FOR DIRECT ACTING PUMPS

Power Supply	Type of Motor
For Constant Speed Service Centrifugal Pumps	
Direct current	Compound wound
A.C. single-phase	Commutator type
A.C. two or three-phase	
	Squirrel cage up to 500 hp.
	Slip-ring, 550 hp. and up
	75-hp. and larger synchronous motors
For Positive Displacement Pumps	
Direct current	Compound wound
A.C. single phase	Commutator type
A.C. two and three phase	
	5 hp. and smaller, squirrel cage
	40 hp. and smaller, wound rotor self starting
	All capacities, slip ring motors
For Variable Speed Service, Centrifugal Pumps and Positive Displacement Pumps	
Direct current	Compound wound
A.C. single phase	Brush-shifting motor
A.C. two and three-phase	
	Brush shifting motor
	Slip-ring when speed reducing is small

Good Motor Control Is Essential

Efficient operation of a motor-driven pump depends largely on the manner in which the motor is controlled. Control equipment is either hand or magnetically operated, subdivided into equipment for starting and equipment for starting and speed regulating. For pumps that run for long periods and the speeds of which must be changed to conform to rapidly fluctuating demands for the liquid delivered by the pump, pressure-regulator controls are available.

Reciprocating Pump Drives

Reciprocating steam driven pumps of various types possess wide range of speed over the range of their capacity. Regulation can be effected either by hand or by some form of pressure or pump regulator or speed governor. Capacity of direct-acting steam pumps is equal to the piston displacement minus the slip, which is about 3 to 5 per cent in a properly packed pump. An automatic stop valve is often recommended to stop the pump in case of breakage of the discharge main.

For proper control and satisfactory operation, pumps should be properly erected and connected. On large pumps, flanged fittings are used, on small sizes, screw joints are satisfactory but in any case, the suction and discharge piping should not put any strain on the pump either by its weight or expansion. The suction line should be installed without air pockets, it should not extend too near the bottom of the well where foreign matter may clog it but it should be submerged about four times the diameter for large pipes and two or three feet for small ones. Suction pipe should be of such diameter that velocity of flow will not exceed 240 ft. per min.

TABLE I, SHOWING NORMAL SPEEDS OF SEVERAL TYPES OF PUMPS, NOT INCLUDING CENTRIFUGALS

Stroke, in.	Direct-acting pumps									
	Piston pumps Plunger and ring pumps and outside center-packed				Pressure pumps, wet vacuum pumps geared power pumps		Boiler feed pumps and pumps for thick liquids		Crank and flywheel pumps	
	Simple cylinder and compound		Triple-expansion							
	r.p.m.*	ft. per min	r.p.m.*	ft. per min	r.p.m.*	ft. per min	r.p.m.*	ft. per min	r.p.m.	ft. per min
3	80	40	..	..	64	32	40	20	..	....
4	75	50	..	..	60	40	38	25	..	....
5	72	60	..	..	58	48	36	30	..	....
6	65	65	..	..	52	52	33	33	..	....
8	56	75	..	..	45	60	29	38	..	....
10	48	80	54	90	38	64	24	40	..	....
12	45	90	50	100	36	72	23	45	90	180
15	40	100	44	110	32	80	20	50	80	200
18	37	110	40	120	29	86	18	55	75	220
24	30	120	33	130	24	96	15	60	60	240
30	25	125	28	140	20	100	13	63	50	250
36	23	135	25	150	18	108	11	68	45	270
48	18	145	20	160	15	116	9	73	36	290
60	15	150	17	170	12	120	7.5	75	30	300

*R.p.m. = cycles per min.

Vacuum chamber on the suction side of the pump is an advantage for long or high suctions and especially for simplex pumps, fire pumps and short stroke high speed pumps. The actual suction lift or head for water that constitutes safe practice is shown in Table II. Hot water must always flow to the pump under a positive suction head. Whenever a pump takes liquids from a system of piping under pressure or the pump is below

TABLE II. SUCTION LIFTS PERMISSIBLE. MINUS AND PLUS SIGNS INDICATE SUCTION LIFT AND SUCTION HEAD RESPECTIVELY

Minimum Allowable Head in Ft. on Suction	Temperature of Water in Degrees F.														
	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210
At sea level	-22	-20	-17	-15	-13	-11	- 8	- 6	- 4	- 2	0	+ 3	+ 5	+ 7	+10	+12
At 2000 alt.	-19	-17	-15	-13	-11	- 8	- 6	- 4	- 2	+ 1	+3	+ 5	+ 7	+10	+12	+15
At 4000 alt.	-17	-15	-13	-10	- 8	- 6	- 4	- 1	+ 1	+ 3	+5	+ 7	+10	+12	+14	...
At 6000 alt.	-15	-13	-11	- 8	- 6	- 4	- 2	+ 1	+ 3	+ 5	+ 7	+10	+12	+14	+16	...
At 8000 alt.	-13	-11	- 9	- 6	- 4	- 2	0	+ 3	+ 5	+ 7	+ 9	+12	+14	+16	...	...
At 10,000 alt.	-11	- 9	- 7	- 4	- 2	- 0	+ 2	+ 4	+ 7	+ 9	+11	+14	+16	+18	...	...

the source of supply, a gate valve is needed in the suction line close to the pump, to permit inspection, cleaning and repair also to control the capacity to a certain extent although it is considered better practice to throttle the discharge side.

A foot valve on the suction pipe increases the friction but keeps the pump primed when idle, otherwise priming must be done by ejector, by a priming system or other means. A strainer on the suction pipe will

help protect the pump from clogging, resulting in serious damage. The foot valve should have a port area twice that of the suction pipe and the strainer three to four times. When a stop valve is in the suction line, a small spring relief valve set at 25 lb. pressure is often installed between pump and stop valve to prevent pressure building up on the suction system.

Velocity in the discharge pipe should not exceed 300 ft. a min. for best results. The line should be of ample size with as few fittings as possible. To provide a shock absorber in the discharge line an air chamber is used; it is a necessity for all single acting pumps and for all crank and flywheel pumps. The volume of the air chamber should be 6 to 8 times the piston displacement for crank and flywheel or single direct-acting pumps and three to four times the displacement for duplex pumps. Gage glasses and suitable air cocks should be installed on air chambers.

Near the pump outlet on the discharge pipe, a check valve should be installed with a gate valve on the outboard side of it. The check valve prevents the pump from running backward if the prime mover stops, also it protects the pump from excessive pressure. A gate valve is necessary for starting a centrifugal pump and for repairing all types. In the discharge pipe of every power-driven positive displacement pump, a relief valve should be placed next to the pump, to protect it from breakage caused by closing of the main discharge valve.

For quick starting, a priming pipe connected to a water supply above the pump is a convenience and in the case of centrifugal pumps, fire pumps and most positive displacement pumps, a necessity; centrifugal pumps may be primed by steam or air ejectors on the pump casings.

Horsepower required to pump water against a total head H is WH ÷ 33,000 where W = 60 Q × 62.4, Q being flow in cubic feet per sec. If E is the mechanical efficiency of the pump, the shaft horsepower is WH ÷ (E × 33,000) which is also the horsepower of the motor or other engine driving the pump. If E^1 is the efficiency of the driving mechanism, the input of the latter is WH ÷ (EE^1 × 33,000).

Storage of Water in Industrial Plants

STORAGE UNDER PRESSURE, SERVICE AND EMERGENCY PROVISIONS, FIRE SUPPLY, TYPES OF TANKS, TANK CAPACITIES

WATER is stored for various purposes in the industrial plant. It is stored under pressure in accumulators to supply hydraulic equipment; it is stored for fire service; it is stored, hot or cold, for general process use; it is stored as boiler feed makeup or as reserve supply and so on. Aside from its storage for use in the power plant proper, which will not be discussed here, storage for use in the industrial departments depends to a large extent on the processes and services in which it is needed.

TABLE I. CAPACITIES OF RECTANGULAR TANKS FOR EACH FOOT OF DEPTH

Width of tank	Length of tank: 2 feet	2 feet 6 inches	3 feet	3 feet 6 inches	4 feet	4 feet 6 inches	5 feet	5 feet 6 inches	6 feet	6 feet 6 inches	7 feet
ft.in.											
2 0	29.92	37.40	44.88	52.36	59.84	67.32	74.81	82.29	89.77	97.25	104.73
2 6	.....	46.75	56.10	65.45	74.80	84.15	93.51	102.86	112.21	121.56	130.91
3 0	.....	.....	67.32	78.54	89.77	100.99	112.21	123.43	134.65	145.87	157.09
3 6	.....	.....	.....	91.64	104.75	117.82	130.91	144.00	157.09	170.18	183.27
4 0	.....	.....	.....	.....	119.69	134.65	149.61	164.57	179.53	194.49	209.45
4 6	.....	.....	.....	.....	.....	151.48	168.31	185.14	201.97	218.80	235.63
5 0	.....	.....	.....	.....	.....	.....	187.01	205.71	224.41	243.11	261.82
5 6	.....	.....	.....	.....	.....	.....	.....	226.28	246.88	267.43	288.00
6 0	.....	.....	.....	.....	.....	.....	.....	.....	269.30	291.74	314.18
6 6	.....	.....	.....	.....	.....	.....	.....	.....	.....	316.05	340.36
7 0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	366.54

Width of tank	7 feet 6 inches	8 feet	8 feet 6 inches	9 feet	9 feet 6 inches	10 feet	10 feet 6 inches	11 feet	11 feet 6 inches	12 feet
ft.in.										
2 0	112.21	119.69	127.17	134.65	142.13	149.61	157.09	164.57	172.05	179.53
2 6	140.26	149.61	158.96	168.31	177.66	187.01	196.36	205.71	215.06	224.41
3 0	168.31	179.53	190.75	202.97	213.19	224.41	235.63	246.85	258.07	269.30
3 6	196.36	209.45	222.54	235.63	248.73	261.82	274.90	288.00	301.09	314.18
4 0	224.41	239.37	254.34	269.30	284.26	299.22	314.18	329.14	344.10	359.06
4 6	252.47	269.30	286.13	302.96	319.79	336.62	353.45	370.28	387.11	403.94
5 0	280.52	299.22	317.92	336.62	355.32	374.03	392.72	411.43	430.13	448.83
5 6	308.57	329.14	349.71	370.28	390.85	411.43	432.00	452.57	473.14	493.71
6 0	336.62	359.06	381.50	403.94	426.39	448.83	471.27	493.71	516.15	538.59
6 6	364.67	388.98	413.30	437.60	461.92	486.23	510.54	534.85	559.16	583.47
7 0	392.72	418.91	445.09	471.27	497.45	523.64	549.81	575.99	602.18	628.36
7 6	420.78	448.83	476.88	504.93	532.98	561.04	589.08	617.14	645.19	673.24
8 0	.....	478.75	508.67	538.59	568.51	598.44	628.36	658.28	688.20	718.12
8 6	.....	.....	540.46	572.25	604.05	635.84	667.63	699.42	731.21	763.00
9 0	.....	.....	.....	605.92	639.58	673.25	706.90	740.56	774.23	807.89
9 6	.....	.....	.....	.....	675.11	710.65	746.17	781.71	817.24	852.77
10 0	.....	.....	.....	.....	.....	748.05	785.45	822.86	860.26	897.66
10 6	.....	.....	.....	.....	.....	.....	824.73	864.00	903.26	942.56
11 0	.....	.....	.....	.....	.....	.....	.....	905.14	946.27	987.43
11 6	.....	.....	.....	.....	.....	.....	.....	.....	989.29	1032.3
12 0	.....	.....	.....	.....	.....	.....	.....	.....	.....	1077.2

For water supply to hydraulic presses and other high-pressure hydraulic equipment, water is stored under pressure by accumulators that supply the demands when they are in excess of the pump capacity. When they are less than pump capacity, the surplus water is stored in the accumulator until its capacity is reached, when the pumps are bypassed and run idle.

CONSTRUCTION OF THE ACCUMULATOR

Hydraulic accumulators consist of a long-stroke, single-acting plunger working in a hydraulic cylinder and loaded in some manner so that when water is pumped in against this load, energy is stored which may be given up later when press valves are opened. The most common type is the weight loaded accumulator, in which the plunger carries a tank filled with scrap, punchings or other heavy material or else a pile of segmental weights supported on a weight holder. The plunger may be stationary with the cylinder the moving member, a scheme often used in small accumulators.

Pressure loaded accumulators, consisting of a hydraulic cylinder and plunger in tandem with a single-acting air cylinder, are occasionally used. Steam may be used but is subject to condensation losses not present with air.

Care must be used in erecting accumulators to provide liberal foundations, and to check the weights at the bottom of the stroke by springs, relief holes and other safety devices. It is not advisable to distribute the total accumulator capacity of a given system between two independent units, owing to the difficulty of loading them so that they will rise and fall together, although by a shifting counterpoise on a triangular frame or by

lashing counterweights together much can be accomplished. It is much simpler, however, to have one big accumulator.

Fire Protection Supply

Storage provisions for automatic sprinkler or fire protection systems must insure an adequate or reliable supply, ample and complete distribution and proper protection from freezing. Overhead gravity tanks of wood staves or steel as shown in Fig. 2 are often used. The size is usually determined individually by the insurance authorities. For sprinklers only, the tank must have a capacity of 10,000 to 25,000 gal. and for both sprinklers and hose of 30,000 gal. Elevated gravity

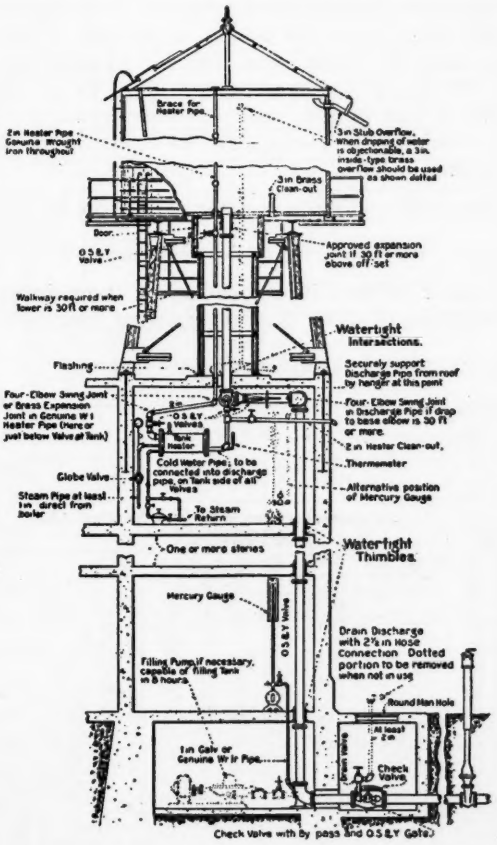

Brace for Heater Pipe
2in Heater Pipe Genuine Wrought Iron throughout
3in Stub Overflow, when dripping of water is objectionable, a 3in. inside-type brass overflow should be used as shown dotted
3in Brass Clean-out
Door
O.S.&Y. Valve
Approved expansion joint if 30 ft or more above off-set
Walkway required when tower is 30ft or more
Watertight Intersections.
Flashing
Securely support Discharge Pipe from roof by hanger at this point
Four-Elbow Swing Joint or Brass Expansion Joint in Genuine W.I. Heater Pipe (here or just below Valve at Tank)
Four-Elbow Swing Joint in Discharge Pipe if drop to base elbow is 30 ft or more.
O.S.&Y. Valves
Tank Heater
2in Heater Clean-out
Cold Water Pipe; to be connected into discharge pipe, on tank side of all valves
Thermometer
Globe Valve
Alternative position of Mercury Gauge
Steam Pipe at least 1in direct from boiler
To Steam Return
One or more stories
Watertight Thimbles
Mercury Gauge
O.S.&Y. Valve
Drain Discharge with 2½in Hose Connection. Dotted portion to be removed when not in use
Filling Pump if necessary, capable of filling Tank in 8 hours.
Round Man Hole
At least 2in
1in Galv or Genuine W.I. Pipe
Check Valve
Check Valve with by pass and O.S.&Y. Gate)

FIG. 2. DETAILS OF A GRAVITY STORAGE TANK USED FOR FIRE SUPPLY OR GENERAL SERVICE WATER

tanks must have a discharge pipe of 6-in. size for tanks up to 25,000 gal. and 8-in. for 30,000 to 110,000 gal. This pipe must be flanged cast iron or wrought pipe with flanged connections.

An important provision for an outside tank whether for fire systems or general service storage is provision against freezing. A common arrangement consists of a tubular steam heater to which a connection is made from the base of the discharge pipe. The heated water is carried up to the tank by a separate pipe.

This arrangement permits the temperature of the coldest water to be observed readily. The coldest water should not go below 40 or 50 deg.

Pressure tanks for fire or other service, Fig. 3, are ordinarily kept two-thirds full of water, says the Piping

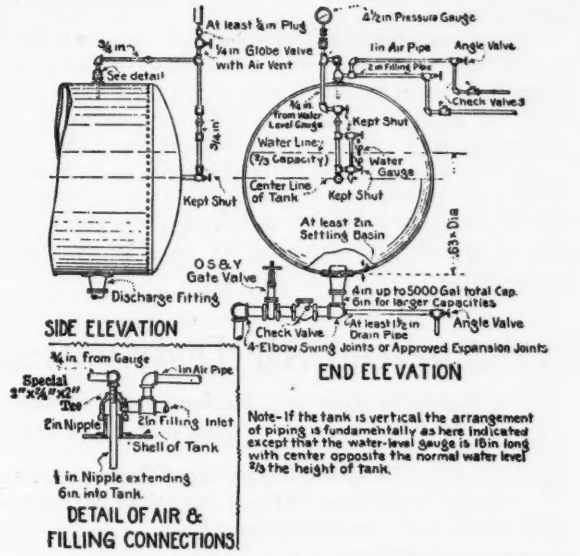

At least ¼in Plug
4½in Pressure Gauge
¼in Globe Valve with Air Vent
1in Air Pipe
Angle Valve
See detail
2in Filling Pipe
Check Valve
¼in from Water Level Gauge
Kept Shut
Water Line (⅔ Capacity)
Water Gauge
Center Line of Tank
Kept Shut
At least 2in Settling Basin
63in Dia
O.S.&Y. Gate Valve
Discharge Fitting
4in up to 5000 Gal total Cap. 6in for larger Capacities
SIDE ELEVATION
Check Valve
At least 1½in Drain Pipe
Angle Valve
4-Elbow Swing Joints or Approved Expansion Joints
END ELEVATION
¾in from Gauge
1in Air Pipe
Special 2"x¾"x2" Tee
2in Nipple
2in Filling Inlet
Shell of Tank
¼ in Nipple extending 6in into Tank.
Note-If the tank is vertical the arrangement of piping is fundamentally as here indicated except that the water-level gauge is 18in long with center opposite the normal water level ⅔ the height of tank.
DETAIL OF AIR & FILLING CONNECTIONS

FIG. 3. DETAILS OF AIR PRESSURE TANK FOR SPRINKLER SYSTEMS AND OTHER INDUSTRIAL PURPOSES

Handbook, with an air pressure on the surface of the water of 75 lb. plus three times the pressure of the column of water in the sprinkler system above the tank bottom. Capacity of such tanks is usually 4500 to 9000 gal. per tank and is usually set by the local insurance authorities. Construction of the tank usually must be according to the Rules for Construction of Unfired Pressure Vessels of the A.S.M.E. and appliances include air compressor usually of 16 to 20 c.f.m., suitable relief valves, and water supply of about 65 g.p.m.

General Service Water Storage

For storage of general service water, as noted above, the conditions of each process usually determine the type of equipment. Overhead steel tanks of 100,000-gal. capacity are common for this purpose, sometimes arranged so that part of the water cannot be discharged except to the fire pumps. Concrete tanks buried underground below frost line are used for storage in many cases. Water treating systems often incorporate large storage tanks for treated water, while cooling ponds also provide some storage. If the flow of the river from which the process water is taken is steady through the year, that will affect the situation. One large rayon plant stores 90-deg. process water in large steel tanks in its boiler house. The methods are infinitely varied.

Table I gives capacities of rectangular tanks for convenience in designing storage, while Table II gives

TABLE II. CAPACITY OF PIPES AND CYLINDRICAL TANKS OF DIAMETERS SHOWN IN GALLONS PER FOOT OF LENGTH

Feet	Inches											
	0	1	2	3	4	5	6	7	8	9	10	11
0	.....	.0408	.1632	.3672	.6528	1.020	1.469	1.999	2.611	3.305	4.080	4.937
1	5.875	6.895	8.000	9.18	10.44	11.79	13.22	14.70	16.32	17.99	19.75	21.58
2	23.50	25.50	27.56	29.74	31.99	34.31	36.72	39.21	41.78	44.43	47.16	49.98
3	52.86	55.86	58.93	62.08	65.30	68.58	71.97	75.44	78.99	82.63	86.35	90.13
4	94.00	97.96	102.0	106.1	110.3	114.6	119.0	123.4	128.0	132.6	137.3	142.0
5	146.9	151.8	156.8	161.9	167.1	172.4	177.7	183.2	188.7	194.3	199.9	205.7
6	211.5	217.4	223.4	229.5	235.7	242.0	248.3	254.7	261.1	267.7	274.3	281.1

Feet	Inches				Feet	Inches				Feet	Inches			
	0	3	6	9		0	3	6	9		0	3	6	9
7	287.9	300.8	320.6	353.9	16	1304	1351	1400	1448	25	3672	3746	3820	3896
8	376.0	399.9	424.5	449.8	17	1498	1548	1599	1651	26	3972	4048	4126	4204
9	475.8	502.7	530.3	558.5	18	1704	1757	1811	1866	27	4285	4365	4445	4526
10	587.5	617.7	647.7	678.0	19	1921	1977	2034	2092	28	4608	4689	4772	4856
11	710.9	743.6	777.0	811.1	20	2150	2209	2269	2330	29	4941	5027	5113	5200
12	846.0	881.7	918.0	955.1	21	2391	2452	2513	2576	30	5288	5376	5465	5555
13	992.9	1032	1071	1111	22	2644	2708	2774	2841	31	5648	5738	5830	5923
14	1152	1193	1235	1278	23	2908	2976	3045	3114	32	6018	6111	6206	6302
15	1322	1365	1412	1457	24	3184	3255	3327	3399	33	6398	6495	6594	6695

capacities of pipes and cylindrical tanks in gallons per foot of length.

Engineers often need to know the time required to empty tanks. An open tank whose cross-section is uniform throughout its depth will empty itself through an orifice or a pipe in just twice the time required to discharge the same amount of liquid under the initial head, if there is no inflow and if the discharge point is at the level of the tank bottom. For other shapes of reservoirs, the time may be computed by dividing the volume into several layers and computing the time for each layer to discharge under the average head for that layer.

Compressed Air Distribution

Air Flow Calculation. Factors That Affect Velocity, Pressure and Quantity of Flow

FLOW OF AIR through pipes for different sizes and velocities is given in Table I, the values having been calculated by the use of the formula

$$Q = 0.3273\ d^2v$$

where d = diameter of the pipe in inches
and v = velocity of flow in feet per second

Atmospheric pressure, hence unit volume of air, varies with the altitude and rise in temperature reduces the unit volume, therefore, in calculating air problems it is necessary to make proper allowance for such conditions. Figure 1 provides a ready means for correcting for altitude and temperature. As an example in the use of this chart, suppose the weight of a cubic foot of air at 100 deg. F. and 14.4 lb. abs. be desired. From the lower curve the weight of a cubic foot of air at 14.7 lb. and 100 deg. F. is found to be 0.071. To obtain the weight at 14.4 lb. abs., select the corresponding multiplier which, by the curves near the center of the chart, is found to be 0.979.

Then $0.071 \times 0.979 = 0.0695$ lb. per cu. ft.

TABLE I. VOLUME OF AIR TRANSMITTED IN CUBIC FEET PER MINUTE IN PIPES OF VARIOUS SIZES

Velocity of Flow, Feet per Sec.	Actual Diameter of Pipe, Inches											
	1	2	3	4	5	6	8	10	12	16	20	24
1	0.327	1.31	2.95	5.24	8.18	11.78	20.94	32.73	47.12	83.77	130.9	188.5
2	0.655	2.62	5.89	10.47	16.36	23.56	41.89	65.45	94.25	167.5	261.8	377.0
3	0.982	3.93	8.84	15.7	24.5	35.3	62.8	98.2	141.4	251.3	392.7	565.0
4	1.31	5.24	11.78	20.9	32.7	47.1	83.8	131	188	335	523	754
5	1.64	6.54	14.7	26.2	41.0	59.0	104	163	235	419	654	942
6	1.96	7.85	17.7	31.4	49.1	70.7	125	196	283	502	785	1131
7	2.29	9.16	20.6	36.6	57.2	82.4	146	229	330	586	916	1319
8	2.62	10.5	23.5	41.9	65.4	94	167	262	377	670	1047	1508
9	2.95	11.78	26.5	47	73	106	188	294	424	754	1178	1696
10	3.27	13.1	29.4	52	82	118	209	327	471	838	1309	1885
12	3.93	15.7	35.3	63	98	141	251	393	565	1005	1571	2262
15	4.91	19.6	44.2	78	122	177	314	491	707	1258	1963	2827
18	5.89	23.5	53	94	147	212	377	589	848	1508	2356	3393
20	6.54	26.2	59	105	164	235	419	654	942	1675	2618	3770
24	7.85	31.4	71	125	196	283	502	785	1131	2010	3141	4524
25	8.18	32.7	73	131	204	294	523	818	1178	2094	3272	4712
28	9.16	36.6	82	146	229	330	586	916	1319	2346	3665	5278
30	9.8	39.3	88	157	245	353	628	982	1414	2513	3927	5655

Pressure Loss in Transmission

Loss of pressure in compressed air transmission for different size pipes for pressures ranging from 60 to 125

TABLE II. LOSS OF PRESSURE IN COMPRESSED AIR TRANSMISSION

Delivery, Cu. Ft. of Compressed Air per Min. | Equiv. Delivery, Cu. Ft. of Free Air per Min. | Size of Pipe, Inches. | 1 | 1¼ | 1½ | 2 | 2½ | 3 | 3½ | 4 | 4½ | 5 | 6 | 8 | 10 | 12 | 14 | 16

Loss of Pressure, in Pounds, by Friction in Pipe 1000 Ft. Long.

At 60 Pounds Gage.

9.84	50	18.24	5.06	1.95	.42	.13	.05									
14.73	75		11.34	4.33	.95	.29	.11	.05								
19.64	100		20.16	7.79	1.69	.52	.19	.06	.04							
24.60	125			12.23	2.65	.81	.30	.13	.07	.03						
29.45	150			17.53	3.80	1.16	.44	.19	.09	.05	.03					
34.44	175				5.17	1.58	.59	.26	.13	.07	.04	.01				
39.35	200				6.77	2.09	.78	.36	.17	.09	.06	.02				
49.20	250				10.61	3.24	1.22	.55	.27	.15	.08	.03				
58.90	300				15.20	4.65	1.78	.78	.38	.21	.12	.05	.01			
68.6	350					6.31	2.37	1.07	.53	.29	.17	.06	.01			
78.6	400					8.28	3.11	1.40	.69	.39	.22	.08	.01			
88.4	450					10.47	3.94	1.77	.88	.48	.28	.11	.02			
98.4	500						4.88	2.20	1.08	.60	.34	.14	.03			
118.1	600						7.03	3.17	1.56	.87	.49	.19	.04	.01		
137.5	700						9.52	4.29	2.12	1.17	.67	.27	.06	.02		
156.6	800							5.57	2.75	1.52	.87	.34	.08	.03	.01	
176.5	900							7.08	3.49	1.94	1.17	.43	.09	.03	.01	
196.4	1000							8.77	4.33	2.40	1.37	.54	.12	.04	.02	.01
294.5	1500								9.73	5.39	3.08	1.20	.27	.09	.03	.01
393.7	2000									9.65	5.51	2.16	.41	.16	.06	.03
492	2500										8.61	3.36	.77	.25	.09	.04
589	3000											4.82	1.11	.36	.14	.06
686	3500											6.54	1.50	.48	.19	.09
786	4000												1.98	.63	.25	.11
884	4500												2.51	.79	.32	.15
984	5000												3.10	.99	.39	.18

At 80 Pounds Gage

7.74	50	14.31	3.96	1.53	.33	.10	.03	.01								
11.3	75		8.46	3.26	.71	.21	.08	.03	.01							
15.2	100		15.31	5.92	1.28	.39	.14	.06	.03	.02	.01					
19.4	125			9.64	2.09	.64	.24	.11	.05	.03	.01					
23.2	150			13.79	2.99	.91	.34	.15	.07	.04	.02	.01				
27.2	175				4.09	1.25	.47	.21	.10	.06	.03	.01				
31.0	200				5.34	1.63	.61	.27	.13	.07	.04	.01				
38.7	250				8.32	2.54	.96	.43	.21	.12	.07	.02				
46.5	300				12.01	3.67	1.38	.62	.30	.17	.09	.03				
54.2	350					4.99	1.88	.84	.41	.23	.13	.05	.01			
62.0	400					6.53	2.45	1.11	.54	.30	.17	.06	.01			
69.7	450					8.25	3.13	1.40	.69	.38	.22	.08	.01			
77.4	500					10.81	3.83	1.73	.85	.47	.27	.10	.02			
92.9	600						5.61	2.46	1.22	.68	.39	.15	.03	.01		
108.2	700						7.46	3.37	1.66	.92	.53	.20	.04	.01		
124.0	800						9.86	4.42	2.18	1.19	.69	.27	.06	.02	.01	
139.5	900							5.61	2.77	1.54	.88	.34	.08	.02	.01	
152	1000							6.64	3.29	1.82	1.04	.40	.09	.03	.01	
232	1500							15.41	7.62	4.24	2.43	.95	.22	.06	.02	.01
310	2000								13.62	7.58	4.32	1.69	.39	.12	.04	.02
387	2500									11.79	6.88	2.64	.60	.19	.07	.03
465	3000										9.72	3.79	.87	.28	.11	.05
542	3500										13.25	5.27	1.19	.37	.15	.06
620	4000											6.78	1.55	.49	.19	.09
697	4500											8.54	1.97	.66	.25	.11
774	5000											10.55	2.46	.77	.30	.14

COPYRIGHT 1906 INGERSOLL-RAND CO.

Delivery, Cu. Ft. of Compressed Air per Min. | Equiv. Delivery, Cu. Ft. of Free Air per Min. | Size of Pipe, Inches. | 1 | 1¼ | 1½ | 2 | 2½ | 3 | 3½ | 4 | 4½ | 5 | 6 | 8 | 10 | 12 | 14 | 16

Loss of Pressure, in Pounds, by Friction, in Pipe 1000 Ft. Long.

At 100 Pounds Gage.

6.41	50	11.89	3.29	1.28	.27	.08	.03	.01								
9.61	75		7.42	2.87	.62	.19	.07	.03	.01							
12.81	100		13.20	5.11	1.15	.34	.12	.05	.02	.01						
15.81	125			7.75	1.68	.52	.19	.08	.04	.02	.01					
19.22	150			11.42	2.48	.76	.29	.13	.06	.03	.02	.01				
22.39	175				3.36	1.03	.39	.17	.09	.04	.03	.01				
25.62	200				4.43	1.36	.51	.23	.12	.06	.04	.02				
31.62	250				6.72	2.06	.77	.35	.17	.09	.05	.02				
38.44	300				9.95	3.04	1.14	.51	.25	.14	.08	.03				
44.78	350				13.41	4.11	1.54	.69	.34	.19	.11	.04	.01			
51.24	400					5.40	2.06	.92	.45	.25	.15	.05	.01			
57.65	450					6.85	2.57	1.16	.57	.32	.18	.07	.02			
63.24	500					8.21	3.08	1.39	.68	.38	.22	.08	.02			
76.88	600					12.21	4.58	2.14	1.03	.57	.33	.12	.03	.01		
89.56	700						6.19	2.79	1.38	.77	.44	.17	.04	.01		
102.5	800						8.13	3.67	1.81	1.00	.57	.22	.05	.02	.01	
115.3	900						10.23	4.64	2.29	1.27	.76	.28	.06	.02	.01	
126.5	1000						12.39	5.00	2.76	1.23	.88	.34	.08	.03	.01	
192.2	1500							12.81	6.68	3.51	2.03	.78	.18	.05	.02	.01
256.2	2000								11.35	6.61	3.62	1.41	.33	.10	.04	.02
316.2	2500									9.50	5.51	2.14	.49	.16	.06	.03
384.4	3000									14.04	8.11	3.16	.76	.23	.09	.04
447.8	3500										10.95	4.26	.98	.31	.12	.05
512.4	4000										14.48	5.59	1.30	.41	.16	.07
576.5	4500											7.04	1.84	.52	.21	.09
632.4	5000											8.51	1.93	.63	.25	.11

At 125 Pounds Gage

5.26	50	9.88	2.70	1.05	.23	.07	.03	.01								
7.89	75	22.20	6.07	2.37	.51	.16	.06	.03	.01							
10.51	100	39.50	10.82	4.22	.91	.28	.10	.05	.02	.01						
13.15	125		16.88	6.58	1.42	.43	.16	.07	.04	.02	.01					
15.79	150		24.33	9.47	2.04	.63	.23	.11	.05	.03	.02	.01				
18.41	175		33.05	12.90	2.78	.85	.32	.14	.07	.04	.02	.01				
21.05	200			16.84	3.63	1.11	.42	.19	.09	.05	.03	.01				
26.30	250			26.30	5.68	1.73	.65	.29	.15	.08	.05	.02				
31.58	300			37.90	8.18	2.51	.94	.42	.21	.12	.07	.03				
36.81	350				11.08	3.39	1.27	.58	.28	.16	.09	.04	.01			
42.10	400				14.51	4.44	1.67	.75	.37	.21	.12	.05	.01			
47.50	450				18.38	5.61	2.11	.95	.47	.26	.15	.06	.01			
52.60	500				22.68	6.95	2.61	1.18	.58	.32	.18	.07	.02			
63.20	600					10.00	3.76	1.69	.84	.46	.27	.10	.02	.01		
73.70	700					13.60	5.11	2.31	1.14	.63	.36	.14	.05	.01		
84.20	800					17.80	6.68	3.01	1.49	.83	.47	.18	.04	.01	.01	
94.70	900						8.45	3.81	1.88	1.04	.60	.23	.05	.02	.01	
105.1	1000						10.42	4.71	2.32	1.29	.74	.29	.07	.02	.01	
157.9	1500						23.48	10.59	5.23	2.90	1.65	.64	.15	.05	.02	.01
210.5	2000							18.81	9.30	5.15	2.94	1.15	.26	.08	.03	.02
263.0	2500							29.40	14.52	8.05	4.60	1.80	.41	.13	.05	.02
315.8	3000								20.90	11.59	6.63	2.59	.60	.19	.07	.03
368.1	3500								28.51	15.78	9.01	3.53	.81	.26	.10	.04
422.0	4000									20.61	11.80	4.61	1.06	.34	.13	.06
473.0	4500									26.10	14.90	5.83	1.34	.43	.17	.08
526.0	5000									32.20	18.45	7.20	1.65	.53	.21	.10

For longer or shorter pipes the friction loss is proportional to the length, *i.e.*, for 500 ft., ½ of the above; for 4,000 ft., four times the above, etc.

lb. gage and for different velocities of transmission is shown in Table II.

Bends in pipes affect the flow of air. It is customary to allow for such bends in terms of length of pipe as follows, in which D is the diameter of the pipe and L is the length of straight pipe in diameters whose effect is equivalent to the bend.

Radius of elbow	5D	3D	2D	1½D	1¼D	1D	¾D	½D
L	7.85	8.24	9.03	10.36	12.72	17.51	35.09	121.2

Effect of Pipe Fittings on Flow

Reduction of pressure caused by globe valves, tees and elbows is likewise accounted for in terms of additional pipe length, in which the reduction of pressure

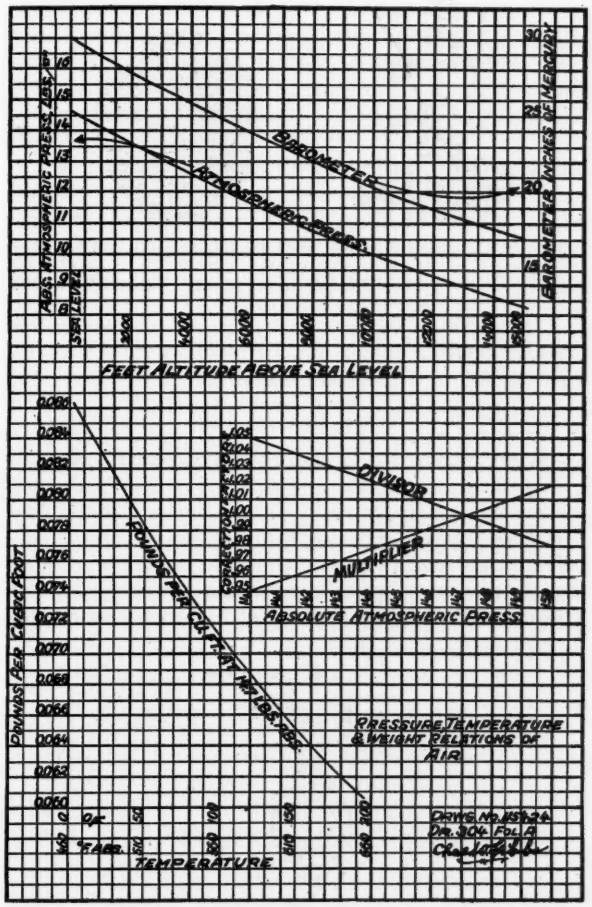


FIG. 1. PRESSURE TEMPERATURE AND WEIGHT RELATIONS OF AIR

produced by a globe valve is the same as that caused by an additional length of pipe l:

$$l = 144D^2 \div [D + 3.6]$$

where D is the pipe diameter in inches.

The reduction of pressure produced by a tee or elbow is equal to ¾ of that caused by a globe valve. These additional lengths of pipe equivalent to globe valves, tees and elbows must be added in each case to the actual length of straight pipe in determining pressure loss from Table II.

Regulation of Compressed Air

Control of Air Compressor Speeds, Application of Unloaders. Moisture Removal Methods

ADOPTION of motor drives for air compressors forced the design of compressors capable of operating at speeds much above those of a few years ago. High speed led to new valve designs such as the wafer valve, which is a thin flat ring usually made of special alloy steel resting upon a carefully ground seat.

Rotative speeds submitted by the Compressed Air Society as representing the maximum in good practice for present designs of straight-line horizontal belt-driven and steam-driven compressor are: 6-in. stroke, 350 r.p.m.; 8-in. stroke, 300 r.p.m.; 10-in. stroke, 285 r.p.m.; 12-in. stroke, 270 r.p.m.; 14-in. stroke, 245 r.p.m.

Motor-Driven Compressor Automatically Controlled

Motor-driven units such as shown in Fig. 1 are controlled automatically, being fitted with electric self-starters and diaphragm controls so as to start and stop

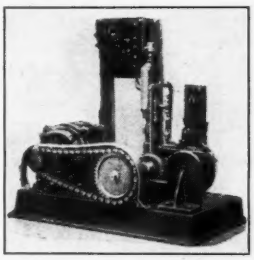


FIG. 1. MOTOR-DRIVEN, AUTOMATICALLY CONTROLLED AIR COMPRESSOR UNIT

automatically at the desired low and high pressure or vacuum point at which the regulator is set. In another type of control in which the compressor is driven by a steam engine, when the compressor unloads, air from the receiver is also admitted to an automatic throttle control which operates a butterfly valve in the intake manifold and the engine is slowed down to idling speed. When the air pressure falls slightly, the compressor takes up its work of compression again and the engine assumes its normal speed.

Unloaders

Many compressors operate at constant speed independent of demands for compressed air. Various types of unloaders have been designed to secure economical operation under this condition. The throttling unloader is a device consisting of a partially balanced valve which is placed at the intake of the compressor for the purpose of shutting off, completely, the intake air when the pressure in the receiver is up to the desired maximum and opening up the tanks when the pressure has reduced a desired amount. The cut-off valve normally held open by a spring, is operated by an air-tight piston under the control of a pilot valve which opens at a designated pressure to admit air to the piston, thus closing the intake valve.

Intake regulation consists of a diaphragm-operated balanced valve, which, by controlling the amount of opening of the valve, is able to hold a constant pressure

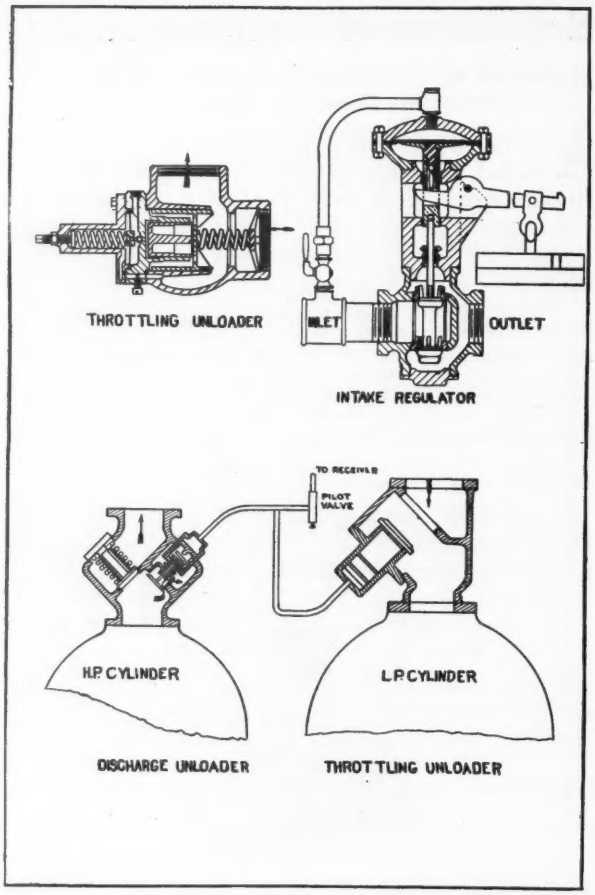


FIG. 2. THROTTLING, INTAKE AND DISCHARGE TYPES OF UNLOADERS

on either the intake or discharge side of the compressor depending upon which is required. Discharge line unloading is always used in conjunction with the throttling unloader as shown in Fig. 2. It consists of a balanced atmospheric valve and a check valve located in the discharge pipe from the compressor. The unloader is under the control of the pilot valve which controls the throttling unloader and the atmospheric discharge valve is opened simultaneously with the closure of the intake valve.

Another type of unloader automatically regulates the air pressure by unseating the inlet valves at maximum pressure and reseating them at minimum pressure.

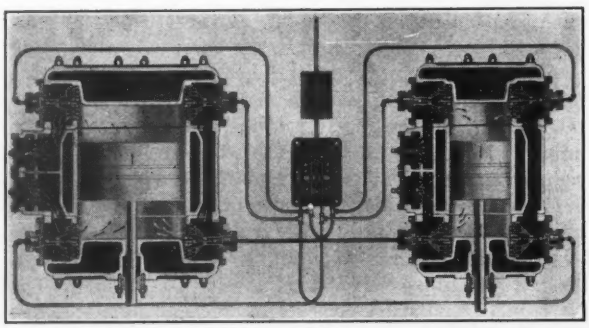


FIG. 3. CLEARANCE-POCKET CONTROL SHOWING ARRANGEMENT FOR FIVE-STEP REGULATION

Governors which operate on the suction pipe cause a compressor to pump under a vacuum when unloaded resulting in oil being sucked into the cylinder and pumped into the discharge line. Fuller description of unloaders is given in the October 15, 1930 issue.

Operation of thermostats, hygrostats and certain regulators by means of compressed air requires uniform

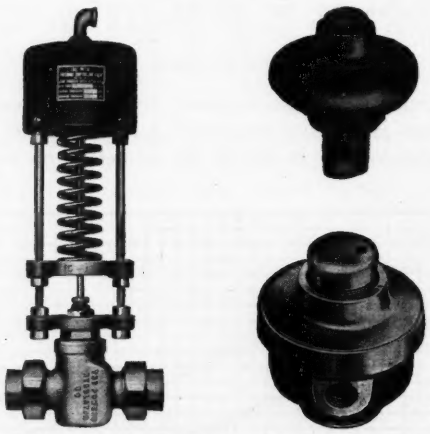


FIG. 5. PRESSURE-REDUCING AND RELIEF VALVES USED IN COMPRESSED AIR SERVICE. PRESSURE REDUCING VALVE, LEFT AND LOWER RIGHT; AIR RELIEF VALVE UPPER RIGHT

pressure, hence reducing and air-relief valves of various types shown in Fig. 5, are employed.

Safety Appliances

Safety valves are installed on air receivers as protection against excessive pressure. The A.S.M.E. code recommends safety valves for air receivers to be so proportioned that the relieving capacity of the valve is sufficient to prevent a rise of pressure in the vessel of more than 10 per cent above the maximum allowable working pressure. Proper installation of air compressors also

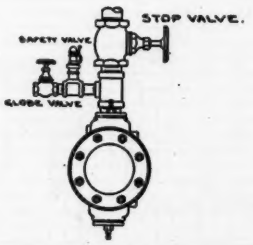


FIG. 6. PROPER MANNER OF CONNECTING SAFETY VALVE TO COMPRESSOR

requires provision against excessive pressure. For this purpose, a safety valve followed by a globe valve is fitted to the tee connecting the stop valve with the cylinder as shown in Fig. 6.

Moisture Removal

Much of the trouble with water in air lines can be overcome if small air receivers are put in the lines at frequent intervals to act as collecting tanks. Instead, moisture traps, which are now in the market or which may be constructed of pipe fittings as shown in Fig. 7, may be used. A moisture trap made of fittings should

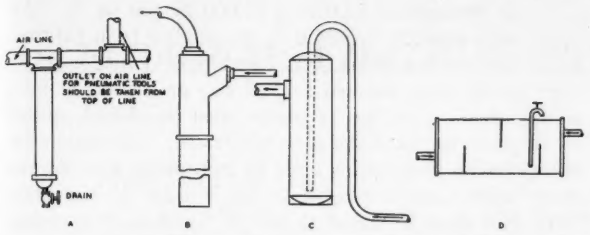


FIG. 7. VARIOUS TYPES OF MOISTURE TRAPS THAT CAN BE MADE OF PIPE FITTINGS

have the top connection and the drop leg several sizes larger than the pipe line. All hose connections to air tools preferably should be made at the top of the distributing line to avoid carrying any moisture to the tools. Where collecting tanks are used, they should be drained at frequent intervals to get rid of the water.

Moisture in the air is always a source of trouble where the air is to be used in a reciprocating mechanism, for this moisture, carried into the machines with the air, tends to wash away the lubricant and to increase the wear by leaving bare surfaces in moving contact. Particularly is this true in high-speed machines such as pneumatic hammers and drills, air motor hoists and sand rammers, where the wearing surfaces are necessarily limited in size and wear may result in greatly increased air leakage hence in considerable loss in economy.

After Cooling

By cooling the air before it passes to the air receiver or pipe line so as to condense and deposit moisture contained in it, these troubles are reduced. The air aftercooler has been devised to perform these cooling and drying functions by bringing the hot moist air from the compressor discharge in contact with water-cooled surfaces of such extent and for such a period of time that the moisture in the air will be condensed and deposited before it can enter the distribution system. The aftercooler should be placed between the compressor and the air receiver and out of doors, if possible.

Use of Tanner-Gas for removing moisture from air by direct contact with it is the most recent method developed. It is described fully in the December 1 issue.

Compressed Air Storage

Air Receivers. Use of Aftercoolers, Air Dryers and Oil Removers

COMPRESSED-AIR receivers are employed to supply a reservoir of air; to equalize the pulsations in the air coming from the compressor; to collect water and grease held in suspension by the compressed air as it leaves the compressor; to reduce the friction of the air in the pipe system and to cool the air as thoroughly as possible before entering the transmission system. Receivers should be of ample capacity, located near the compressor and outside of the engine room, if possible.

To find the proper size of receiver for a compressor, the maximum capacity of the compressor in free air per minute—piston displacement per minute will do—must be determined, then the volume this air will occupy at the working pressure, which will represent the volume of the receiver, must be calculated. This will give the minimum size but in making a selection a larger one is preferable.

Receivers Should Be Ample in Size

There is advantage in having the receiver overly large; many troubles are caused, on the other hand, by receivers that are too small to overcome fluctuation in pressure or to keep the air stationary long enough to cool and deposit part of its moisture. The cubical contents of an air receiver should be from 1/6 to 1/10 of the free air capacity per minute of the air compressor with which it is used.

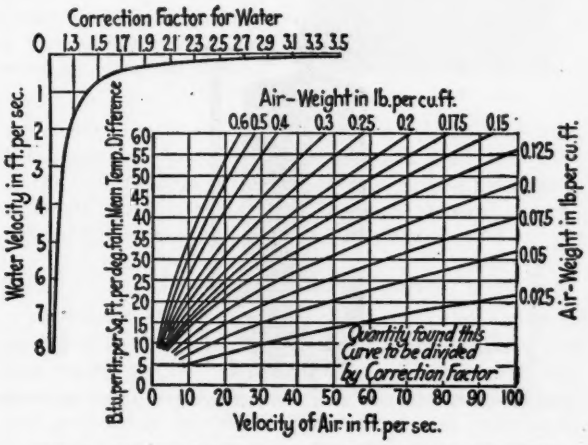

Correction Factor for Water
0 1.3 1.5 1.7 1.9 2.1 2.3 2.5 2.7 2.9 3.1 3.3 3.5
Water Velocity in ft. per sec.
Air-Weight in lb. per cu. ft.
0.6 0.5 0.4 0.3 0.25 0.2 0.175 0.15
Btu per ft. per sq. ft. per deg. Fahr. Mean Temp. Difference
0.125
0.1
0.075
0.05
0.025
Air-Weight in lb. per cu. ft.
Quantity found this Curve to be divided by Correction Factor
Velocity of Air in ft. per sec.

FIG. 1. HEAT TRANSFER RATE IN AFTER COOLERS

To facilitate the removal of water from the compressed air, the receiver is frequently equipped with a coil or pipe, serving as an aftercooler, through which cool water flows. The amount of water required for air at 80 to 100 lb. pressure is as follows:

Temp. of cooling water, deg. F.....	50	60	70	80	90
Gal. per min. per 1000 cu. ft. of free air per min.....	120	140	160	180	200

Heat Transfer in Aftercoolers

Heat transfer in B.t.u. per hour per square foot of heating surface per degree F. mean temperature difference between the air and water with different air velocities in feet per second for aftercoolers is shown in Fig. 1. Thus for an air velocity of 50 ft. per sec. and air density of 0.2 lb. per cu. ft., the heat transfer rate obtained

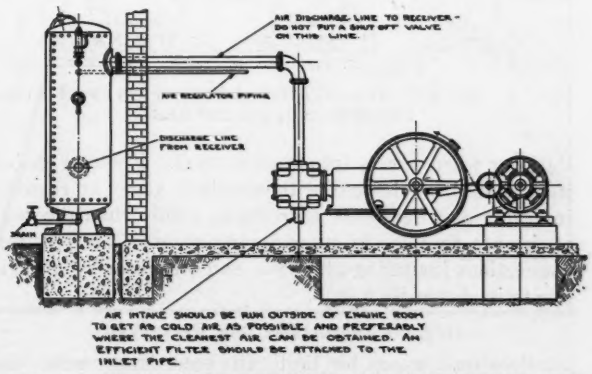

AIR DISCHARGE LINE TO RECEIVER - DO NOT PUT A SHUT OFF VALVE ON THIS LINE.
AIR REGULATOR PIPING
DISCHARGE LINE FROM RECEIVER
AIR INTAKE SHOULD BE RUN OUTSIDE OF ENGINE ROOM TO GET AS COLD AIR AS POSSIBLE AND PREFERABLY WHERE THE CLEANEST AIR CAN BE OBTAINED. AN EFFICIENT FILTER SHOULD BE ATTACHED TO THE INLET PIPE.

FIG. 2. CONNECTIONS BETWEEN AIR COMPRESSOR AND RECEIVER

from the curve is about 48 B.t.u. This value must be corrected for the velocity of the water. Assuming the latter to be 1 ft. per sec., the correction factor, from the curve, is 1.4. The corrected heat transfer rate is, therefore, 48 ÷ 1.4 = 34 B.t.u.

Air receivers should be installed on blocks or foundations so as to avoid contact with the ground as dampness causes excessive corrosion around the bottom. The bottom seams, especially, should be kept clean and well covered with paint. The discharge pipe from the compressor should be connected to a point near the top of the receiver as shown in Fig. 2 and the air transmission line should be connected at a lower point. When the transmission pipe line is long, receivers should be placed at both ends of the line.

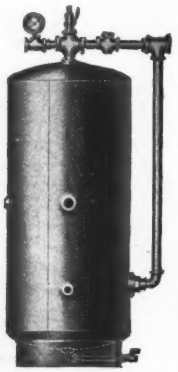


FIG. 3. AIR DRYER AND OIL REMOVER ATTACHED TO AIR RECEIVER

Drainage should be provided as shown at the lowest point of the receiver to permit drawing off accumulated oil, water and impurities which gather there, at regular interval. This also provides a check on the lubrication,

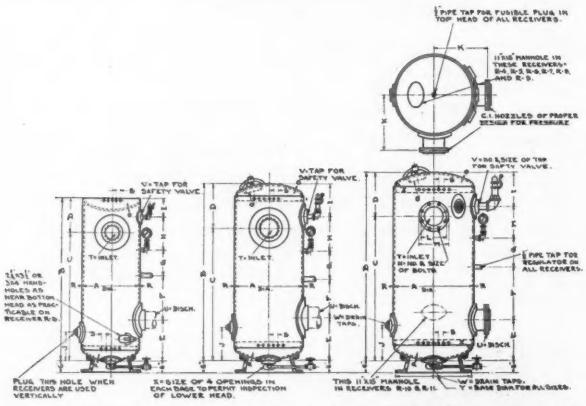


FIG. 4. A.S.M.E. STANDARD CONSTRUCTION FOR COMPRESSED AIR RECEIVERS

showing when excess lubricant is used. Pressure gages used should be checked with standard gages at regular intervals and necessary corrections made when discrepancies are found. Another arrangement of air receiver connections including air dryer and oil removing attachments is shown in Fig. 3.

Specifications for Air Receivers

Receivers must be built in accordance with the A.S.M.E. code for unfired pressure vessels as indicated in Fig. 4. They should be made of flange steel having a tensile strength of 55,000 to 65,000 lb. per sq. in. All rivet holes must be punched ⅛ in. smaller than full size for plates not exceeding $\frac{5}{16}$ in. thick and ¼ in. for plates over $\frac{5}{16}$ in., then reamed to full size or drilled at once to full size. All edges of plates must be planed, milled or chipped; no bevel shearing is allowed. All outlets for safety valves and drains must be reinforced with forged steel boiler flanges riveted to the outside of the shell. Receivers must be tested to 188 lb. hydrostatic pressure for 125 lb. working pressure. All joints must be caulked properly on the outside of the shell. Where the plates are not thick enough to give the required number of threads, all pipe taps in the shell except those for drains must be reinforced with plates riveted on the inside.

The Possibility of America as Seen by Steinmetz

IT took less than six years to transform the late Charles Proteus Steinmetz from a raw young German immigrant into a naturalized American citizen who not only was passively willing to accept legal obligations toward his adopted country but was quick to become a practical missionary in its interest when occasion offered. This was revealed by a Steinmetz letter, just discovered by his foster son, Joseph LeRoy Hayden, in going through some of Steinmetz's papers at the Steinmetz home in Schenectady, N. Y.

The letter was written January 9, 1895, not long after Steinmetz had become a fully naturalized United States citizen, and 5½ yr. after his arrival in this country. It was addressed to Eskil Berg, brother of one of Steinmetz's engineer friends at the main office of the General Electric Co. Berg was then living in Sweden, his native country, and had been considering the idea of coming to America. He is now living in Schenectady.

Steinmetz unreservedly urged Berg to cast loose from Europe and think only of America as the place to live and work. He wrote:

"Now the matter is this: Come over at once, without wasting any more time in Europe. There is nothing to be got there, everything here. You had better start with the idea that you will never go back except for a visit. I never saw a sensible man who had lived a few years in the United States willing to go back to Europe to stay. By the way, you will have to work here, and a good deal of it, but there is plenty of time left to have a good time, thus come over at once. Best regards and hoping to see you soon personally,

"Yours,

"Charles P. Steinmetz."

Commenting on business prospects, H. C. Turner, president of Turner Construction Co., says: "Business must shortly resume its normal upward swing and those persons will be fortunate who utilize present opportunity to strengthen their relative business position.

"Not since 1922 have we constructed buildings at such low prices as during this year and, in my judgment, the moment it becomes clear that business is improving cost of buildings will increase. There can be no better time than the present to consider new building, what it will cost, when it should be started and how long it will take to build. These facts are essential for a sound decision."

ELECTRICAL DISTRIBUTION SYSTEMS

BY OTTOMAR H. HENSCHEL

Educated at Armour Institute and Marquette University, Mr. Henschel was for 6 yr. with Sheboygan Ry. & Elec. Co., 2 yr. in charge of plants for Central Illinois Elec. Co., 7 yr. Associate Editor of Power Plant Engineering, 6 yr. plant engineer for Federal Pressed Steel Co. and is now engaged in consulting engineering on industrial plants.

TYPES AND PRECAUTIONS FOR SAFETY AND ECONOMY.

EXISTING conditions and requirements together with possible future expansion should be given due consideration in the design of the industrial plant electrical distribution system.

This may be fed from an engine room switchboard (where energy is locally generated) or where purchased energy is utilized directly from the outside lines of the serving utility or through the medium of a substation. Obviously, local conditions dictate the selection.

Where direct current is employed, the distribution system may be of the two or of the three-wire type. In alternating-current systems of distribution, there are the two-wire or three-wire single-phase systems; the three-wire or the four-wire two-phase systems (now practically obsolete); and the three-wire and four-wire, three-phase systems. Of these the most commonly used at the present time is the three-phase, three-wire system, although there is evidence of the more general adaptation of the three-phase, four-wire system.

DIRECT-CURRENT SYSTEMS

These are still in use in many installations wherein energy is carried but comparatively short distances and also where utilities may be serving direct-current districts which frequently exist in close proximity to central generating stations. Three wires are principally used for feeders and mains.

As a rule, the neutral wire is of the same size as each

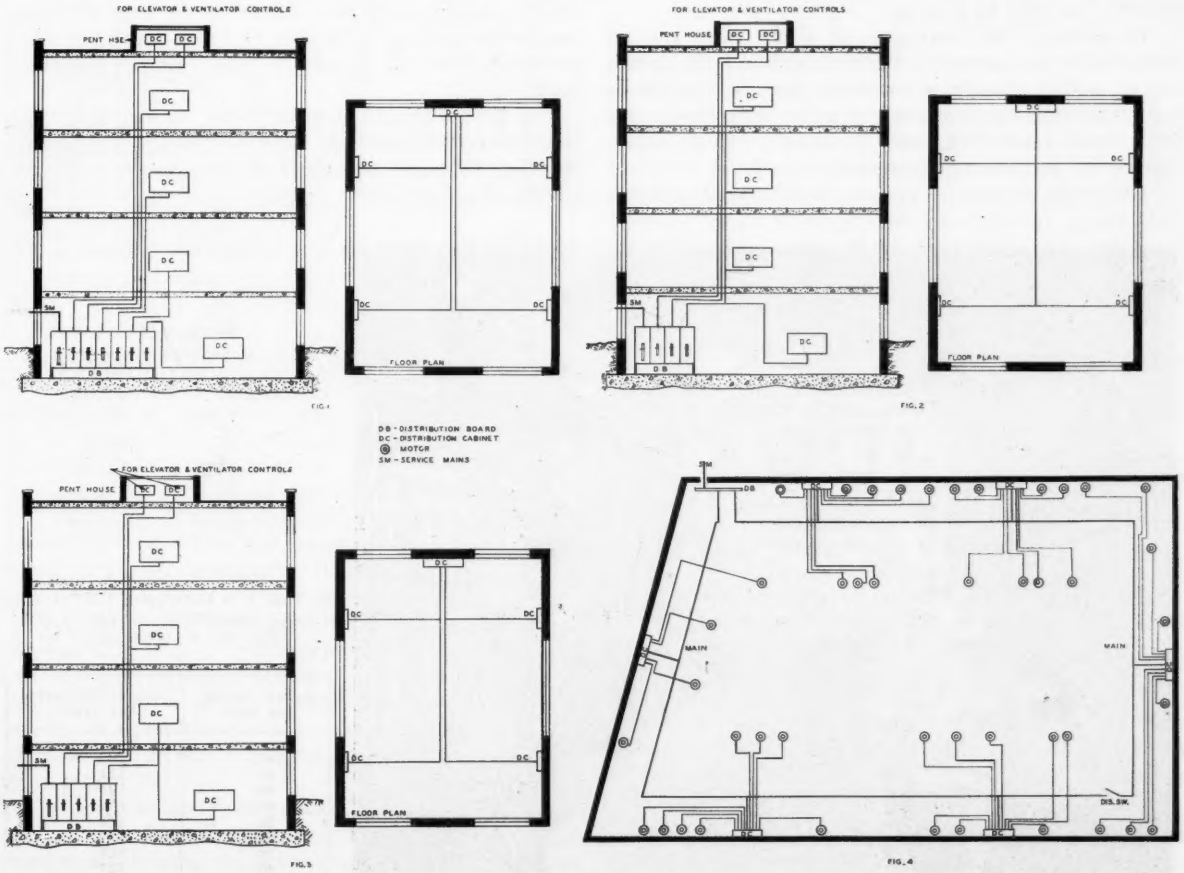


FIG. 1. INDUSTRIAL BUILDING DISTRIBUTION SYSTEM OF THE MULTIPLE FEEDER TYPE FIG. 2. INDUSTRIAL BUILDING DISTRIBUTION SYSTEM OF THE TREE TYPE FIG. 3. INDUSTRIAL BUILDING DISTRIBUTION SYSTEM OF THE COMBINED MULTIPLE FEEDER AND TREE TYPES FIG. 4. TYPICAL RING DISTRIBUTION SYSTEM

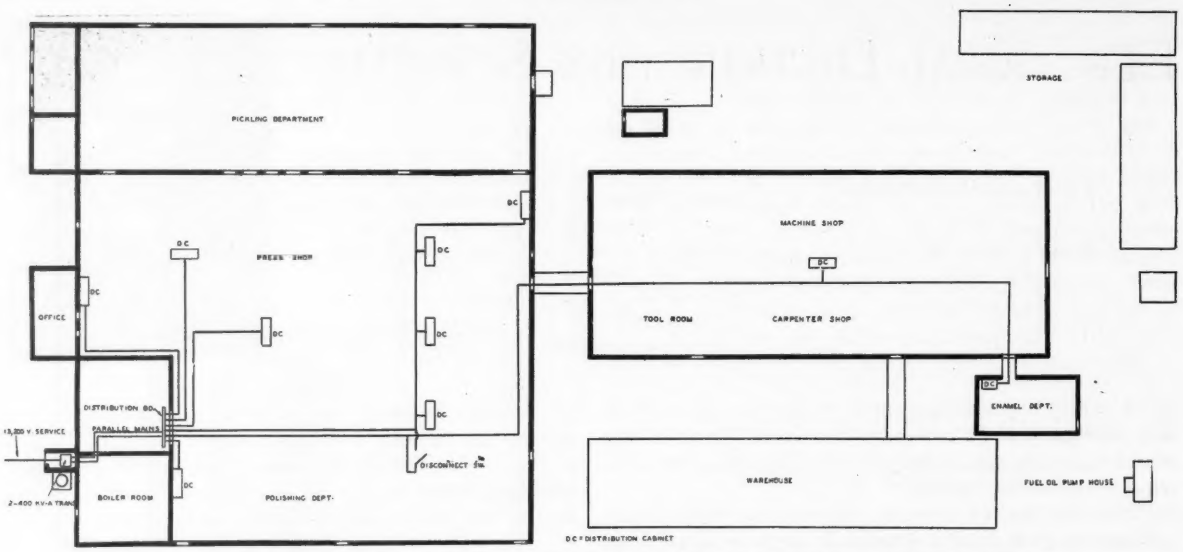


FIG. 5. TYPICAL INDUSTRIAL PLANT COMBINATION MULTIPLE FEEDER AND TREE SYSTEM

of the two outer wires because, if one of the outer fuses should blow, one side of the system would be loaded and the other side unloaded. Obviously, such an occurrence would cause the neutral to carry considerably more than normal current with consequent resulting overload. With the neutral grounded and of a cross section equal to that of each of the outside lines, the neutral fuse may be omitted.

Occasionally the neutral is of a size twice that of each of the outside wires. With such design, the system can be readily changed to two-wire. In fact, the scheme is particularly recommended in a two-wire system fed by a local generating plant but tied in with utility service for purpose of emergency.

Obviously, three-wire systems should be always balanced as nearly as possible, although an unbalance of from 10 to 15 per cent is permissible. With excessive unbalance unequal voltage results.

Single-Phase Systems

These, as in the case of direct-current systems, may be of the two-wire or three-wire type. Except to meet special requirements they are primarily used for lighting service and, as in the case of direct-current systems, precautions should be taken to insure proper balance of load.

In the industrial plant of today, single-phase lighting systems are generally supplied through the medium of oil or air-cooled transformers connected to one of the phases of a three-phase system.

FIG. 6. INTERIOR OF TYPICAL INDUSTRIAL PLANT SECONDARY SUB-STATIONS

TABLE I. VARIATION OF COPPER REQUIREMENTS WITH VARIATION OF POWER FACTOR

Power Factor Per Cent	Copper Required Per Cent
100	100
95	111
90	124
85	135
80	156
75	178
70	204
65	237
60	278
55	330
50	400

Fundamentally, industrial and in fact all commercial plant distribution systems may be classified as: (A) Tree system; (B) Multiple feeder system; (C) Ring system; or a combination of any two or all of them.

Ordinarily the first results from gradual plant expansion, although in no few instances such expansion can also well result in the employment of the multiple feeder plan.

Obviously, however, the third or ring arrangement is one which must be so designed and constructed as to care for any predetermined ultimate load which it may be required to care for. Of course reënforcement by means of a second or even a third multiple connected ring or rings can always be resorted to, an arrangement, however, not generally desirable from a practical standpoint. In this case switching has a tendency to become more or less complicated.

TABLE II. MAXIMUM NUMBER OF HORSEPOWER PERMITTED TO BE CONNECTED TO ANY GIVEN SIZE OF MAIN OR BRANCH CIRCUIT

Size of Wire	Direct-Current Motors Maximum Permissible H.P.		Three Phase A. C. Motors Maximum Permissible H.P.	
A. W. G.	110 V.	220 V.	220 V.	440 V.
14	2	4	6	12
12	2.7	5.3	8	16
10	3.3	6.7	10	20
8	4.7	9.3	14	27
6	6.7	13.3	20	39
4	9	19.0	27	55
3	11	21	31	62
2	12	24	35	70
1	13	27	39	78
0	17	33	49	97
00	20	40	59	117
000	23	47	68	137
0000	30	60	88	176
250,000 c. m.	33	67	97	195
300,000 c. m.	37	73	108	216
350,000 c. m.	40	80	117	234
400,000 c. m.	43	87	127	254
500,000 c. m.	53	106	156	312
600,000 c. m.	60	120	176	352
700,000 c. m.	67	133	195	390
800,000 c. m.	73	147	215	430
900,000 c. m.	80	160	234	468
1,000,000 c. m.	87	173	254	508
1,100,000 c. m.	92	184	269	539
1,200,000 c. m.	97	195	285	570
1,300,000 c. m.	103	205	301	602
1,400,000 c. m.	108	216	316	633
1,500,000 c. m.	113	227	332	664
1,600,000 c. m.	119	237	348	695
1,700,000 c. m.	124	248	363	727
1,800,000 c. m.	129	259	378	757
1,900,000 c. m.	135	269	394	789
2,000,000 c. m.	140	280	410	820

Figures 1, 2 and 3 portray typical loft building distribution systems of the multiple feeder, tree and a combination of these two types. In Fig. 4 is shown a typical ring installation, in which feed is possible from either one or both ends, selective switches being provided for the purpose. With this scheme and especially where oil circuit breakers are employed, these may be readily isolated for inspection and repair without plant service interruption. A disconnect switch located as shown may prove desirable from an operation standpoint.

Typical combined multiple feeder and tree system is illustrated by Fig. 5. Mains are of such capacity as to care for future plant growth and resulting load increase amply. Between service transformers and main distribution board, multiple lines are used. These are carried overhead and except for drops to cabinets are of open construction.

In order to insure continuity of service at all times and to care for any switching equipment emergency those mains feeding the more important equipment can at any time be interconnected through the medium of a disconnect switch provided for the purpose.

Increasing Existing System Capacity

Not infrequently, distribution systems appear overloaded, or voltage regulation may be exceedingly poor.

Ordinarily, under such conditions reënforcements are installed or the entire system is rebuilt. This should, however, be done only after a thorough survey has been conducted for, in no few instances, low power factor may be the underlying cause of the trouble. The reason for this is apparent from Table I indicating increases of copper requirements with decrease of power factor.

Thus, for example, it is evident that where a system is operating apparently overloaded but at a power factor of approximately 70 per cent, an increase in system capacity of about 100 per cent may be secured by raising the power factor to unity.

Capacity Determinations

No empirical formula or rules can be presented covering the economics of conductor size determination.

TABLE III. VALUES OF CONSTANT K FOR USE IN DETERMINATION OF VOLTAGE DROP IN ALTERNATING-CURRENT CIRCUITS

SYSTEM	POWER FACTORS				
	1.00	.95	.90	.85	.80
	Values of K				
Single phase	21.6	24.0	27.0	.30	34.0
Three phase, three wire	18.7	20.8	23.4	26	29.4

Suffice it to state that when consideration is taken solely of initial cost, it will always be found cheaper to run a few large conductors rather than a greater number of smaller ones. Ordinarily, however, none larger than 1,000,000 circular mils should be installed and, if greater capacity is called for, parallel conductors are to be preferred. In alternating-current work, none larger than 700,000 circular mils should be used, in order to eliminate otherwise detrimental skin effects.

Care should also be taken in the case of alternating-current lines to install all conductors comprised in the circuit in a single iron conduit. With the use of a single conduit for each conductor, the inductance bound to be set up will cause undue heating and low power factor.

Maximum number of horsepower that should be grouped upon any main or branch supplying a group of motors is given in Table II prepared by the Department of Gas and Electricity of the City of Chicago.

In alternating-current work, voltage drop may be determined by dividing, the product of a constant K (see Table III), the length of each conductor in feet and the maximum anticipated current in amperes, by the cross sectional area of the conductor in circular mils.

In any single-phase system, the line current amperes is equal to load in watts divided by, the product of the power factor of the load expressed as a decimal and the voltage at the load.

In a three-phase system, this current value may be determined by dividing the load in watts by, the product of 1.73, the power factor of the load expressed as a decimal, and the voltage at the load.

Electric Distribution Circuit Practice

METHODS OF WIRING. DETERMINATION OF LOAD CURRENT, CONDUCTOR SIZE, VOLTAGE DROP. EFFECT OF INDUCTANCE. METHODS OF PROTECTION, FUSES, CIRCUIT BREAKERS, USE OF LIGHTNING ARRESTERS

DISTRIBUTION of electrical energy from the switchboard in the power plant to the point of utilization in the factory, home or office involves the same care and protective effort that would be accorded to the distribution of any other valuable manufactured commodity. It would be obviously poor practice to manufacture certain articles easily damaged or lost in transit and then ship them out of the factory unboxed or uncrated; nor would it be advisable to ship large quantities of such articles without keeping careful records of where they were sent to. Any organization guilty of such carelessness could not expect to stay in business long.

Yet when distributing electrical energy, just such carelessness is often encountered and large blocks of

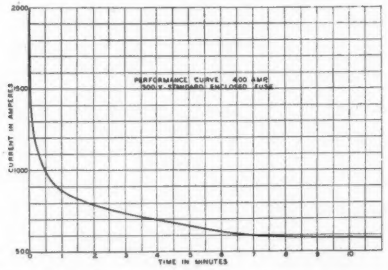


FIG. 1. TYPICAL PERFORMANCE CURVE OF A 400-AMP., 500-V. STANDARD ENCLOSED FUSE

power leave the generating plant without adequate records being kept of where this power goes or how much of it is lost in transmission due to poorly designed or overloaded circuits and inadequate protective equipment. The circuits or conductors form the "crates," so to speak, in which the electrical units are sent to their destination and unless these "crates" are large enough or properly designed, a considerable proportion of these units may be lost. To determine whether or not such units are lost and how many, it is necessary to provide metering equipment.

Thus, the distribution of electricity involves

1. Circuits of proper type and capacity.
2. Protective devices to protect circuits against damage and shutdown.
3. Provision for metering and recording performance.

While there are a great many different types of circuits in use, varying both as regards physical design and in electrical characteristics, yet there are certain fundamental factors underlying the design of all circuits which must be adhered to if maximum economy and reliability are to be expected from their use.

IMPORTANT FACTORS IN SELECTION OF CONDUCTORS

The three most important of these factors are: 1. The wire or conductor should be of such size that it will carry the electrical energy to the point where it is to be used without an excessive drop or loss of voltage. 2. It (the conductor) must be large enough so that the current will not heat it to a temperature that would damage or destroy the insulation or cause fire in surrounding materials. 3. The resistance of the conductor must be such that the cost of the energy lost in transmission, due to the current overcoming the resistance, (the I^2R loss) will not be excessive. A conductor may satisfy one of these three conditions yet not satisfy the remaining two. Hence, all three must receive consideration.

Thus, the design considerations of both direct current and alternating current circuits have to do mainly with the problem of determining the most suitable size of conductors. In the case of direct current circuits this is a fairly simple matter and usually, in the case of the length of alternating current circuits encountered in industrial practice, the procedure for alternating current circuits is not very much more complicated. In the case of long a.c. lines, the factors of inductance and capacity enter in and make the design more difficult.

In laying out a circuit, the general procedure for both a.c. and d.c. circuits involves

(a) Determination of the circuit current in amperes.
(b) Determination of the length of circuit to the approximate center of load if the load is not concentrated at one end.
(c) Fixing the allowable voltage drop.
(d) Calculation (by means of proper formulae) of the size of wire such that the voltage drop of (c) will not be exceeded.
(e) Checking this wire size for current carrying capacity, i.e., against overheating.
(f) Checking wire size for energy loss or energy dissipated in overcoming line resistance, which should be within reasonable limits.

The load to be supplied with energy in many cases consists of only one or two units (motors, lamps, heating devices, etc.) and in such cases the kilowatt load will be quite definitely known. In other cases of mixed load of considerable magnitude it may be necessary to consider the diversity element of the load, particularly when a considerable portion of it is intermittent in character. Also, in some cases, it is desirable to make an addition to the actual net kilowatt demand in order to provide for future growth. Assuming the load to be known by any consideration such as these, the line current can be readily determined provided the voltage (at which energy is supplied to the load) is known. Then, since (by definition of 1 watt) $P = E\,I$,

$KW = E\,I \div 1000$ and $I = (KW. \times 1000) \div E \ldots (1)$

where I = current in amps. E = line voltage (receiving end voltage) P = power in watts, KW = power in kilowatts.

The line current is thus determined by equation 1.

ALLOWABLE VOLTAGE DROP

The allowable voltage drop should not, generally

speaking, exceed 10 per cent for motor circuits and it is better from an operating point of view not to exceed 5 per cent. For incandescent lamps operating at 110 v. nominal, the voltage at the most remote lamp should not be more than 3 v. below the nominal (110 v.) voltage. Where power is purchased some public service companies do not permit the total voltage drop of the interior wiring system to exceed one volt. Incandescent lamps are exceedingly sensitive to variations in voltage and lamp circuits should be proportioned so that the variation of voltage at the lamps under no circumstances is more than 3 v. for 110-v. lamps or 6 v. on 220-v. lamps. In a motor or mixed load circuit with several branches, the total allowable drop may be arbitrarily apportioned, say 1 v. in individual branches; ⅔ of the remaining drop in the feeders and ⅓ in the mains supplying the feeders. Branch feeders to individual motors should always be figured on the basis of full load current to the motor.

Size of wire to give the allowable voltage drop can be most conveniently calculated by the use of Ohms law ($E = RI$) modified so that the resistance, R, is expressed in terms of the length of the conductor, the circular mils of cross sectional area, and the unit resistance per circular mil foot of copper wire. Taking the latter unit as 11 ohms per cir-mil-ft. (the actual value is from 10.6 to 10.8) which is sufficiently accurate, the following equation results:

$$\text{cir. mils} = 22\ I\ L \div E_1 \quad \ldots\ldots\ldots\ldots (2)$$

in which I = circuit current in amp.; L = one way length of the circuit in ft.; E_1 = drop in voltage in the circuit.

This can be transformed into $E_1 = 22\ I\ L \div$ cir. mils. The size conductor that will give the allowable voltage drop can now be chosen by selecting from any wire tables the nearest commercial gage having an area in cir. mils not less than that given by equation 2.

Carrying Capacity of Conductors

A conductor or circuit may have ample cross-sectional area to carry a given current a given distance without exceeding a maximum specified voltage drop and yet be so small that it will overheat. After a conductor size has been selected with reference to voltage drop as shown above, it should be checked against a table showing the safe current carrying capacities of wires. Such tables are available in any electrical handbook.

In selecting conductor sizes for circuits, the rules of the National Electric Code should be kept in mind. While, in many cases, compliance with these rules is not obligatory, it is nevertheless good practice to follow these rules in regard to conductor sizes. For motor branch circuits, the code requires that conductors be of a size to carry safely a current 25 per cent greater than that required by the motor.

Finally the energy loss or power dissipated in overcoming line resistance should be figured. This loss, generally speaking, should be kept less than 8 per cent, even on comparatively long circuits. The power loss may be computed by the formula

$$P_1 = 22\ I^2L \div \text{cir. mils}$$

in which P_1 = the power lost in overcoming line resistance, I the line current in amperes and L the one way length of the circuit in feet.

The foregoing rules apply equally well to direct and alternating current circuits. In alternating current circuits, in addition there are certain phenomena that must be considered principal among which are the effects of power factor and inductance which creates reactance. Where circuits are short as in branch wiring to motors, the effects need not be considered but where circuits are long, these effects are of considerable importance.

Reactance is present in practically all alternating current circuits. Its effect is to cause a drop in voltage somewhat similar to that caused by resistance and as in the case of resistance, reactance is measured in ohms.

Where all of the wires of a circuit, two wires for a single-phase, four wires for a two-phase and three wires for a three-phase circuit are carried in the same conduit or where they are spaced less than an inch apart, the effect of line reactance may ordinarily be neglected.

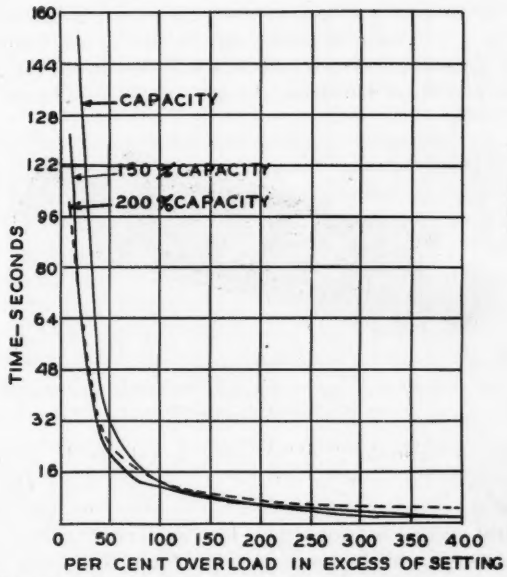


FIG. 2. TIME OVERLOAD CURVES OF SMALL ENCLOSED AIR CIRCUIT BREAKER

Line reactance increases somewhat as the size of the wire decreases and decreases as the distance between wires decreases.

When alternating current conductors are installed in metal conduit, all the wires of one circuit must be carried in the same conduit to eliminate heating and excessive voltage drop due to electromagnetic induction.

When the effect of line reactance can be neglected, that is, in lines in which the circuit wires are all carried in the same conduit or are separated less than one inch, the size of conductors may be arrived at by use of the same formula given for direct current. In figuring the line current, however, the number of phases and the power factor of the circuit must be considered.

For single-phase circuits, the line current is given by the formula

$$I = \frac{\text{kw.} \times 1000}{E \times \text{P. F.}}$$

where P. F. = the power factor of the circuit.

In the case of two-phase, four-wire circuits, the formula for line current becomes:

$$I = \frac{\text{kw.} \times 1000}{E \times \text{P. F.} \times 2} = \frac{\text{kw.} \times 500}{E \times \text{P. F.}}$$

and for three-phase three-wire circuits

$$I = \frac{\text{kw.} \times 1000}{E \times \text{P. F.} \times 1.73} = \frac{\text{kw.} \times 580}{E \times \text{P. F.}}$$

Knowing the line current, the size conductor that will give the allowable voltage drop E_1 for three-phase circuits is determined by the equation

$$\text{Cir. mils} = \frac{11\ I\ L \times 1.73}{E_1} = \frac{19\ I\ L}{E_1} \quad \ldots\ldots\ldots (3)$$

In general, these equations are sufficiently accurate for calculating the usual 220-v. and 440-v. branch motor circuits of medium capacities, where the circuit is only a few hundred feet in length.

In figuring three-wire direct current circuits, it is usually necessary to assume that the circuit is balanced, that is, no current is considered to flow in the neutral wire. Ascertain the current that will flow in the outside wires and then determine the size of the conductor by

FIG. 3. TYPICAL RENEWABLE TYPE OF ENCLOSED CARTRIDGE FUSE

means of formula 2. The drop in voltage E_1 in the formula is the drop in both of the outside wires and is twice the drop to each receiver connected between the neutral and an outside wire. It is evident that the voltage drop E_1 can be twice as great for a three-wire circuit as for the equivalent two-wire circuit. If the three-wire circuit is appreciably unbalanced, separate calculations are made for each conductor. To illustrate this, suppose that a circuit having two No. 3/0 outer wires and a No. 0 for the neutral, 800 ft. long, carries 140 amp. on the positive side and 105 amp. on the negative side; what is the drop on each side of the circuit?

The resistance of 1000 ft. of No. 3/0 wire as given by tables is 0.049 ohm; therefore 800 ft. of this wire will have a resistance of 0.8×0.049 or 0.041 ohms.

Similarly, the resistance of 800 ft. of No. 0 wire is 0.8×0.098, or 0.080 ohms.

Then, since $E = IR = 140 \times 0.041 = 5.7$ v. drop in the positive wire

$E = IR = 105 \times 0.041 = 4.3$ v. drop in the negative wire

$E = IR = 35 \times 0.080 = 2.8$ v. drop in the neutral wire

The drop in the neutral wire is added to the drop on the "heavy" side of the circuit and subtracted from the "lighter" side, making the total drop $5.7 + 2.8 = 8.5$ v. on the "heavy" side and $4.3 - 2.8 = 1.5$ v. drop on the "light" side.

In direct current systems of distribution, there are only two different types of circuits, two-wire circuits and three-wire circuits. The three-wire direct current is the most economical of copper and although its use requires a slightly more complicated layout, it is the more desirable of the two. In alternating current systems of distribution, there are the two-wire and three-wire single-phase systems; the three-wire and four-wire, two-phase systems and the three-wire and four-wire, three-phase systems.

The single-phase system requiring only a minimum number of conductors has the advantage of low first cost. Single-phase feeders, however, require 33 per cent more copper than equivalent three-phase feeders.

Single-phase motors are more complicated and cost more than polyphase motors and usually produce more disturbance of voltage in starting than three-phase machines. The distribution of energy by single-phase circuits is, therefore, usually limited to motor units of less than 10 hp., although in some instances motors up to 35 hp. are used with good success.

Two-phase systems are either three or four-wire, the latter being really two single-phase systems operating 90 electrical degrees apart. The principal advantage of a two-phase system is that there are only two phases to keep balanced and only two transformers are needed to supply polyphase energy to the motors.

Three-phase systems are widely used; in fact, the three-phase system three-wire has become more or less standard in this country. It is well adapted to power distribution and requires but 75 per cent as much copper in the feeder system as an equivalent single-phase system. It has advantages in that any unbalance in the load is carried by the neutral wire.

Methods of Installing and Supporting Conductors

While there are a number of wiring methods available for use in industrial installations, the most satisfactory and the most generally used method today is that employing rigid iron conduit. Flexible metallic conduit is approved for nearly all classes of buildings but it is used principally for wiring finished buildings and for wiring machinery or in other locations where the run changes direction frequently.

Open wiring on knobs and cleats is a cheap and satisfactory method of wiring if it is installed in compliance with the underwriters' requirements. In all cases, the rules of the National Electric Code should be rigidly adhered to and only materials approved by the Code used.

Rigid iron conduit, though higher in first cost, is probably the most economical for permanent installation. Iron conduit is merely standard wrought iron steel pipe, specially treated and is finished either in black, similar to enamel or is zinc coated. An almost endless variety of conduit outlet, switchboxes, elbows supports, hangers and other fittings are available to meet almost any conceivable condition.

Protection of Circuits

In furnishing protection to electric circuits, two conditions should be considered; first, overload and second, over voltage. Where circuits are run for any distance outdoors, lightning protection should also be afforded although that may be classed as a special type of overvoltage. Overload protection is highly essential on all

circuits because of the danger of accidental ground or short circuit.

For overload protection, fuses and circuit breakers are used. Fuses are simple and have the advantage of low first cost, but can not be replaced with the ease that a circuit breaker can be reset. Fuses, however, possess a time element of operation which circuit breakers do not always have unless specially designed. Because of this time element, fuses delay the opening of an overloaded circuit an appreciable amount and if the overload lasts only for a brief instant, the service is not interrupted. Where electrical equipment is under intelligent supervision, as it usually is in power plants and factories, such short overloads are not harmful and the fact that service is maintained saves much time and money.

Many circuit breakers on the market, however, possess similar characteristics and where the first cost can be justified, such breakers possess several advantages over fuses. At the present time, there are available a number of ingeniously designed small air circuit breakers, totally enclosed, which may be used to protect individual motors or circuits feeding groups of motors or lights. Those breakers are designed both for straight instantaneous overload protection as well as for continual overload protection. A curve showing the characteristics of one of these breakers is shown in Fig. 2.

Circuit breakers may further be furnished with "no-voltage" protection. In the case of lighting circuits, a loss and then a resumption of voltage results in no damage but in the case of large motors a contrary condition prevails. Such motors usually have to be started through a resistance and if when the voltage is restored after an interruption, the motor is still connected to the circuit, full voltage impressed across the windings may seriously damage them. With a circuit breaker having no voltage protection, the motor is disconnected from the circuit at once in case the voltage fails and before its operation can be resumed it must be started by hand.

Another advantage of circuit breakers in the protection of motors is on polyphase circuits. Where fuses are employed in the protection of polyphase equipment, the blowing of one fuse may leave the equipment connected to the circuit on only one or two phases, resulting in damage and unbalance of the circuit. In the case of a polyphase circuit breaker, opening and closing all phases of a polyphase circuit simultaneously this cannot occur. In the event of an overload to, say, one phase of a three-phase circuit, such a breaker will open all three phases.

Fuses used in practice are either open link or enclosed, the latter being made in the renewable or non-renewable type. Open link fuses disrupt violently under short circuits and should be used only enclosed in iron cabinets. They are inexpensive and when so installed render excellent service in industrial plants if they are maintained by reliable electricians. The disadvantage of this type of fuse is that it is easily tampered with and a fuse easily replaced with a piece of copper wire.

Enclosed cartridge fuses are of two types, the ferrule contact type for currents below and including 60 amperes at 600 v., and the knife blade contact type for currents of from 61 to 600 amp. at 250 v. and of from 61 to 400 amp. at 600 v. A cartridge fuse usually consists of a tube of fiber inside of which is placed the fuse link. An insulating powder surrounds the link and fills the tube. In this type of fuse the formation of destructive ares is effectively prevented and the fuses themselves are capable of being rated very accurately.

Renewable fuses are widely used and have decided economic advantages. Because of the inexpensive renewals, they are especially adapted to circuits which have frequent interruptions. The construction of an approved type of enclosed fuse is shown in Fig. 3. It consists of a fiber tube with removable caps and washers together with screws and nuts for fastening a fuse link.

In addition to protection against overload and no voltage, circuits which are run outdoors must be provided with protection against lightning. Various types of lightning arresters are available for circuits of different voltages and characteristics. Among those in common use are the oxide film type, the autovalve type, the multigap type, the compression type and the aluminum cell electrolytic arrester.

Switchboard Construction and Arrangement

ARRANGEMENT OF PANELS, MATERIALS USED, CONSIDERATIONS GOVERNING LOCATION

IN ANY ELECTRICAL SYSTEM where electricity is generated, distributed, transformed and utilized to any considerable extent, there is some point in the wiring where the control of the installed equipment is concentrated and arranged in a manner most convenient for attention and operation. Such an assemblage of control devices, together with the structure on which they are mounted has come to be known as the switchboard.

There are various types of switchboards—some very simple, consisting only of a panel or series of panels on which are mounted simple, manually operated switches; others, very complicated, consisting of arrays of panels and benches equipped with innumerable electrically operated switches, indicating devices, meters, recorders and protective devices. The type of switchboard used, of course, is dependent upon the kind of apparatus to be controlled, the capacity of this apparatus and the types of switchboard devices which are to be used.

For convenience in design, construction and operation, switchboards are divided into section or panels, each one insofar as practicable, controlling a single element or a group of similar elements in the system. Thus a switchboard intended to serve a small generating station, will usually consist of: 1. A generator panel; 2. an exciter panel; 3. a totalizing or metering panel, and 4. one or more feeder panels for distributing the generated power to its various points of use.

Today, switchboard construction has been highly

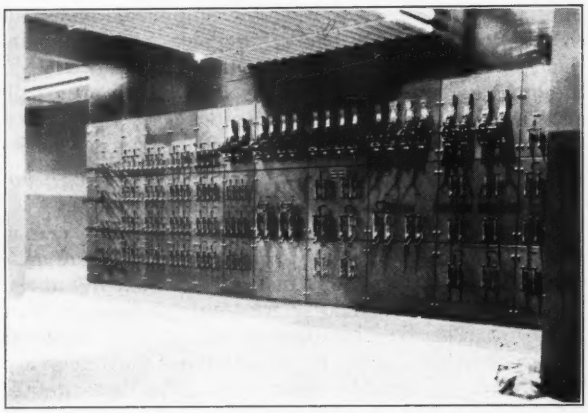


FIG. 1. A DISTRIBUTION BOARD IN THE BASEMENT OF A LARGE NEW YORK OFFICE BUILDING. THE INCOMING LINE BREAKER PANELS ARE IN THE CENTER. FEEDER PANELS ARE ARRANGED ON EACH SIDE

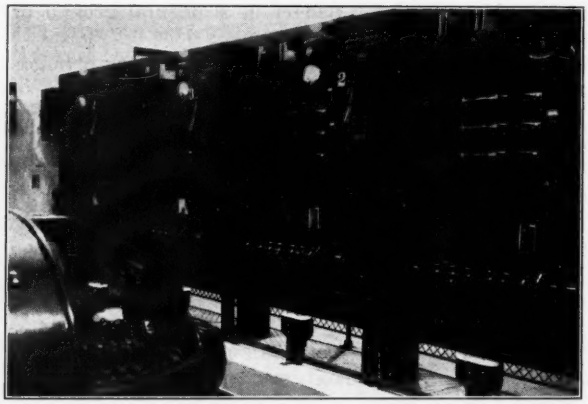


FIG. 3. A CONTACTOR BOARD, USED IN THE STARTING AND AUTOMATIC ACCELERATION OF LARGE MOTORS. NOTE THE ENCLOSED CIRCUIT BREAKERS MOUNTED ON EACH PANEL

standardized and completely equipped panels to suit any of a wide variety of purposes can be obtained from the manufacturers. Any number of such panels may be arranged to suit the requirements of any condition and may be added to whenever necessary.

In laying out a switchboard, the following fundamental considerations should be kept in mind, approximately in the order of their importance:

1. The switching arrangement should not offer an undue risk to the men who have to operate the equipment, particularly under conditions arising from electrical failure of lines and apparatus.

2. The arrangement should provide for the economic operation of apparatus, that is, to permit operation of machines or transformers at any load as near as possible to that corresponding to the maximum efficiency of such apparatus.

3. Simplicity should be adhered to in every element of the design.

4. Coincident with simplicity there should be a reasonable degree of flexibility which has for its object the providing of such a degree of continuity of service as may be commensurate with the class of load.

5. Like all other well designed work, the mechanical arrangement and construction should be rugged and reliable.

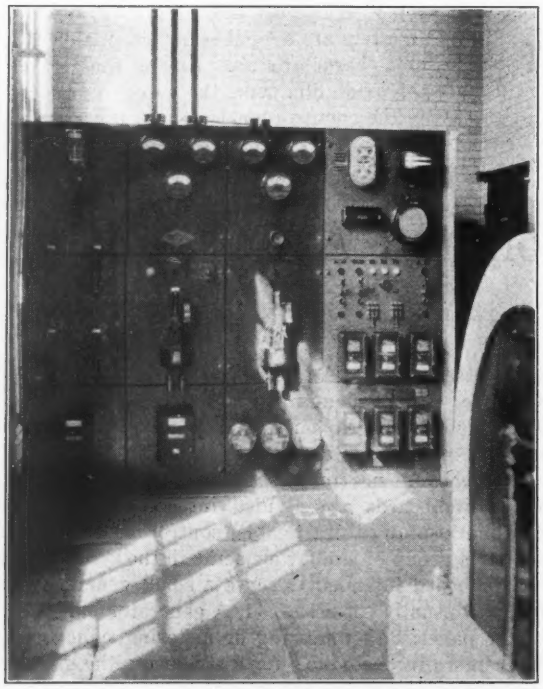


FIG. 2. SWITCHBOARD INSTALLATION IN AN ELECTRICALLY OPERATED ICE PLANT

Materials of Which Switchboards Are Made

Four standard materials are used in the construction of switchboard panels: slate, marble, ebony-asbestos and rolled metal, usually steel. Of these four, slate and rolled steel are the most common in use today. Marble is used primarily where beauty is a factor and where marble more effectively harmonizes with the architecture of the room or building in which the board is installed. In certain office buildings or hotels or other "show places" where the board is under the observation of the general public, marble is used. On the other hand, marble also has insulating qualities that are superior to slate and is sometimes selected for this reason.

Slate, however, is the standard material for switchboard panels where a metal board is not desired. It is furnished either with an oil finish or marine paint. While slate is a good insulator for ordinary voltages, caution must be exercised in using it on high voltages. The maximum limit for primary apparatus carried directly upon natural black slate boards is 1200 v. alternating or direct current. For marine finished slate, the maximum limit for primary apparatus carried directly upon the slate board is 550 v. for direct current and 440 v. for alternating current.

Ebony asbestos panels are available where equipment of higher voltages is to be mounted directly on the switchboard. The usual limit for primary apparatus on this material is 4500 v. This is an excellent material; its great strength per unit of weight as compared to other similar material together with its high atmospheric resisting ability makes it highly desirable. It takes a satisfactory finish.

The steel panel consists of a single section of cold

rolled stretcher leveled steel plate, usually ⅛ in. thick, formed so as to provide channel sections at the sides. Steel has the advantage of lightness and strength, making easy handling of complete panels in one section. The use of steel naturally is confined to the dead front type of board, with all exposed current carrying parts behind the switchboard front. These boards are particularly adapted to use where workmen are constantly in the vicinity of electrical apparatus.

Types for Various Purposes

The switchboard, although essentially an element of the generating or sub-station, has found its way also into the factory and industrial plant, and while its form in the latter application is somewhat different from that found in the power station, its function remains the same. In an industrial plant, the function of the switchboard is entirely one of distribution and as a rule will contain only switches. In Fig. 1, for instance, is shown a switchboard in a large office building. It consists of three central panels containing the air circuit breakers connecting the building system with the outside power lines, and a group of side panels containing the switches to the various building circuits. No meters are provided. A board of this kind, as a rule is not attended continually and therefore, is not fitted with indicating devices.

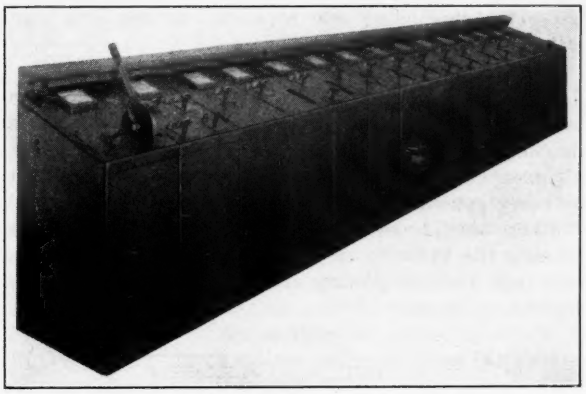


FIG. 4. STEEL BENCHBOARD FOR USE IN A STEEL MILL

In Fig. 2 is shown a different type of board, this being an installation in a commercial ice plant. It consists of: 1, A main station panel (comparable to the generator panel in a generating station) containing an oil circuit breaker together with metering equipment. 2, A synchronous motor starting panel. 3, A low voltage feeder panel, and 4, a metering panel.

For purposes of heavy motor control, and where motors are started, stopped and reversed frequently, as in the case of rolling mill service, a special type of board, more commonly known as a contactor panel, is employed. Contactors, of course, are nothing more than magnetically operated circuit breakers for cutting out resistance as the motors accelerate. While these installations are not always spoken of as switchboards, they are a part of the general classification and the principles of switchboard design are applicable in their construction.

In general, regardless of their application, switchboards may be divided into the following different classes: Live front boards of vertical type and bench type, and dead front designs of the safety enclosed vertical type, sectional and truck type. The truck type of board has come into considerable popularity of late because of its unit construction and the ease with which a defective unit may be removed and replaced. Bench boards are used primarily where the vertical boards cannot be used on account of insufficient space for mounting a required number of devices within a certain optical and operating range. In Fig. 4 is shown a steel benchboard for a steel mill.

Arrangement and Location of Switchboard

In arranging the switchboard, the general idea is to group the component parts as compactly as possible, reducing the width without overcrowding. This has been facilitated by improvements in design of apparatus, a notable example being the rectangular types of instruments and meters which make the most complete use of the panel space occupied. If oil circuit breakers are used, and if they are mounted directly back of the panels, the length of the switchboard is dependent on the size of the breakers. If the breakers are remote mounted and particularly if they are electrically operated, greater advantage may be taken of economies in space occupied by the panel mounted equipment with resulting increased compactness and convenience to the operator.

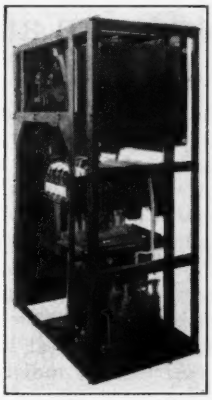


FIG. 5. SAFETY ENCLOSED STATIONARY TYPE PANEL FOR A. C. MOTOR EQUIPMENT. BACK VIEW, SIDE PLATES REMOVED

For use in industrial plants for the control of motors, the safety enclosed type of panel has many advantages. A unit of this type with the side plates removed is shown in Fig. 5.

In the arrangement of panels for various circuits, it is customary to make allowance as far as practicable for future extensions. The circuits not likely to increase in number, such as totalizing, station auxiliaries, etc., are kept near the center of the board. Generator circuits may then be extended by additional panels in one direction, and feeders in the other direction. Where some definite plan can be made for the future, blank panels for circuits expected may be installed.

The location of the switchboard, of course, is dependent upon its use. In a power station, the board is arranged so as to provide the most convenient running of conductors from the generators and to the outgoing lines. In an industrial installation where the board is

intended for the control of motors, it is usually located as closely as possible to the motor itself. This rule may be followed quite generally.

Of course, in settling the location of a switchboard, first consideration must be given to personal safety. Ample space is the best safeguard and for that reason the aisles should always be liberal.

All switchboard equipment unless especially designed should be installed in dry places and where it is free from corroding fumes and dust. Another thing that is not ordinarily thought of when ordering a switchboard from the manufacturer is the altitude at which it is to be used. This is quite important since the insulating quality of air decreases rapidly at high altitudes as well as the current carrying capacity of the apparatus. If a board designed for a normal location is ordered for installation at high altitudes, the manufacturer should be advised accordingly.

Bus Bar Design and Construction

MATERIALS, FACTORS DETERMINING CAPACITY, ARRANGEMENT, MOUNTING

BUSES AND CONNECTION bars for use in switchboard construction are usually of copper, although in some instances aluminum has been used for this purpose. In the early days, buses and connections were designed upon a basis of given amperage per square inch of cross-sectional area, usually 800 or 1000 amp. per sq. in. This, however, is not a logical basis, owing to the varying conditions as regards radiation, proximity of other current carrying parts, skin effect, reactance, etc., and modern practice is that the ampere ratings of bus and connection bars shall be based upon this temperature rather than current density.

Thus, the standard rating of connection bars and buses is based upon a maximum operating temperature of 40 deg. C. This with an ambient temperature of 40 deg. C. limits the permissible rise to 30 deg. C. Above 70 deg. C., the oxidation of copper commences to take place at a very high rate.

In order to keep within the prescribed temperature limits, great care must be exercised in the design of the connection bars, not only to obtain ample cross-sectional area for carrying the current but also to make good joints where necessary. In alternating-current installations, iron parts such as supports, conduits, floor beams, etc., should not be placed between the conductors of a circuit in such a manner as to form magnetic loops around a single conductor. This applies even to reinforcing material in concrete compartments.

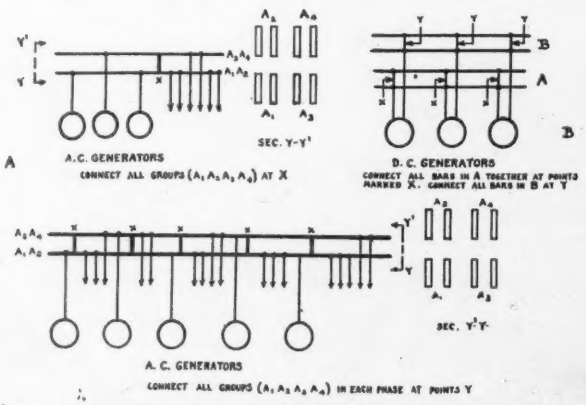


FIG. 1. DIFFERENT BUS ARRANGEMENTS SHOWING POINTS OF INTERCONNECTION

In designing the arrangement of bus bars and determining the proper number, a number of factors must be taken into account. Not only does the current strength enter in but magnetic and radiation effects are important. For high current capacity the buses are arranged in tiers. Different sizes of buses are required for direct current and alternating current. For alternating current, heavier buses are required for 60 cycles than for 25 cycles, this being due to eddy currents and skin effects.

Bus arrangements vary widely according to local conditions. In many cases a single bus is sufficient; in others where continuity of service is paramount, a double bus will be provided. For direct-current buses, all groups of laminations should be connected together at every generator. The studs of switches and circuit breakers should not be used for these interconnections because the capacity of the bus may be such that the exchange current flowing through the stud might be beyond its capacity.

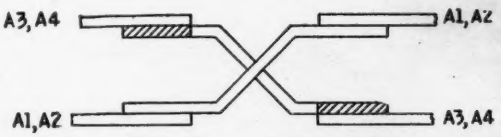
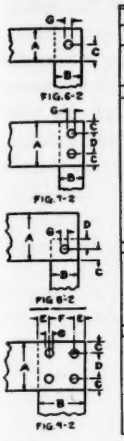


FIG. 2. METHOD OF TRANSPOSING BARS

Alternating-current buses present a more complicated problem. Not only do such buses require to be laminated as in direct-current buses but on account of the skin effect, they should be separated into groups, as shown in Fig. 1. For certain current capacities, four groups are required, sub-divided into two horizontally separated groups (lower A-1 and A-2, and upper A-2 and A-4). When buses are so divided, that is, in four groups, two tiers of laminations on each side are considered as electrically separate units and connections should always be run to both groups of such units. Under some conditions, it is found advisable to parallel all groups of laminations in each phase at one or more points along the bus. Two typical cases where such paralleling would be desirable are:

1. Where several generators are connected to one end of the bus and feeders are taken from the other end. In this case, some of the generators are connected to A-1 and A-2, others to A-3 and A-4; therefore, in order to obtain uniform loading on the bus under all conditions, particularly when one of the generators is shut down, it is necessary to parallel all groups in each phase at some point between the generators and the feeders, as illustrated in Fig. 1A.

2. When several generators are connected to a bus and feeders are taken off between the generator and connections. Here, again, some of the generators are connected to one unit and the remainder to the other. Since the feeders are taken off between the generator connections, it will be necessary to parallel all groups in each phase at each generator as illustrated in Fig. 1C.



Bars A	Bars B	Fig.	C	D	E	F	G	Bolts
1	1	6-2	1/2				15/32	3/8
1 1/2	1		3/4				15/32	3/8
1 1/2	1 1/2		3/4				5/8	1/2
2	1	6-2	1				15/32	3/8
2	1 1/2		1				5/8	1/2
2	2		1				5/8	1/2
2 1/4	1		1 1/8				15/32	3/8
2 1/4	1 1/2		1 1/8				5/8	1/2
2 1/4	2		1 1/8				5/8	1/2
2 1/4	2 1/4		1 1/8				5/8	1/2
2 1/2	1	7-2	1/2	1 1/2			15/32	3/8
2 1/2	1 1/2		1/2	1 1/2			15/32	3/8
2 1/2	2		1/2	1 1/2			15/32	3/8
2 1/2	2 1/4		1/2	1 1/2			15/32	3/8
2 1/2	2 1/2	9-2	1/2	1 1/2	1/2	1 1/2	15/32	3/8
3	1	7-2	5/8	1 3/4			15/32	3/8
3	1 1/2		5/8	1 3/4			15/32	3/8
3	2		5/8	1 3/4			5/8	1/2
3	2 1/4		5/8	1 3/4			5/8	1/2
3	2 1/2	9-2	5/8	1 3/4	1/2	1 1/2	15/32	3/8
3	3		5/8	1 3/4	5/8	1 3/4	15/32	3/8
4	1	8-2	1	1/2			15/32	3/8
4+	1		1	1/2			15/32	3/8
4	1 1/2	7-2	1 1/8	1 3/4			5/8	3/8
4	2		1 1/8	1 3/4			5/8	1/2
4	2 1/4		1 1/8	1 3/4			5/8	1/2
4	2 1/2	9-2	1 1/8	1 3/4	1/2	1 3/4	15/32	3/8
4	3		1 1/8	1 3/4	5/8	1 3/4	15/32	3/8
4	4		1 1/8	1 3/4	3/4	1 3/4	5/8	1/2

FIG. 3. STANDARD BOLTING FOR BUS AND CONNECTION BARS

Where long runs of alternating-current buses are necessary, consideration must be given to the fact that there is a difference in the reactance of the individual laminations which results in unbalancing the current carried, consequently in unequal heating of the bars. It is possible to equalize the current carried by the bars by transposition of the sections on phases as shown in Fig. 2. Where bus runs are not more than 10 ft. long, transposition is not necessary.

What has been said here, of course, refers primarily to heavy bus bar installations. For small installations where the currents are comparatively low, round conductors or even insulated wire is frequently used, as follows:

Bare rod ¼ in. dia.....Up to 75 amp.
Bare rod $\frac{5}{16}$ in. dia.....Up to 150 amp.
Bare rod $\frac{7}{16}$ in. dia.....Up to 200 amp.
Bare rod ½ in. dia.....Up to 300 amp.
Insulated wire No. 1/0 B. & S..Up to 175 amp.
Insulated wire No. 4/0 B. & S..Up to 300 amp.

If rubber covered wire is used for bus bars or connections, it should be covered with a flame proof braid.

Special attention should be given the matter of making joints and connections. The number of joints in connection bars can be minimized by the use of edgewise, bends and twists. When joints are necessary, they should have good clean contacts and the component parts should be firmly secured by means of bolts. Soldered joints are not usually recommended, but sometimes owing to space limitations, it is necessary to make them. In such cases, the connection bars should be riveted and firmly secured mechanically before being soldered. Where connection bars are to be joined together, they can be bolted as shown in Fig. 3.

For fastening connection bars to buses, clamps with bolts are usually used instead of drilling the bars. This provides much greater ease and economy in construction and installation without sacrificing in any way the efficiency of the joint. On direct-current circuits, malleable iron clamps with steel bolts can be used but for alternating-current circuits it is necessary to use clamps of nonmagnetic material with steel belts.

It is essential that the main switchboard wiring for high tension alternating current be insulated and carried on suitable insulators securely mounted on rigid supports. Various types of insulators are available for this purpose. A convenient type of support has a base which permits turning of the insulator at any angle between 0 and 90 deg. and which may be firmly locked in any position by means of bolts. It may be mounted on flat surfaces or ¾ or 1¼-in. pipe.

In mounting bus supports, it is policy first to locate the two which are at the ends of the bus. Then stretch a line between the centers of these supports and mount the necessary intermediate supports in line with the end supports. Where parallel bars are used in a bus of the same phase, ¼-in. spacers must be used between them to permit of proper ventilation.

In places where connections are accessible from aisles, no bare connection above 750 v. should be allowed. For insulating bars, they should be wrapped with a number of layers of varnished cambric, the number of layers depending upon the voltage. Up to 1000 v. , 3 layers is sufficient, from 1000 v. to 3000 v., 4 layers, from 3000 v. to 4000 v., 5 layers, etc. In taping a bar, the required number of layers of cambric are wrapped around the bar and then a good insulating varnish applied to the outside layer. Over this wind one-half lap layer of cotton webbing and then cover this with two coats of flame resisting paint.

Switching Equipment

TYPES, CAPACITIES, ARRANGEMENT, LOCATION AND MOUNTING

FOR THE ACCOMPLISHMENT of the desired results in switching operations a number of different types of devices are available. First, for the very small installation, there are the simple hand-operated knife switches and fuses. For low capacity circuits, and for low voltages these are satisfactory but for circuits of any magnitude, these are replaced by the oil or air circuit breaker.

Air break circuit breakers are either automatic or non-automatic. This type of breaker is used on all direct-current circuits but on alternating current circuits, their use is confined to comparatively low voltages. In capacity, they will range from low values of current up to 4000 or 5000 amp. With the recent development of the De-ion grid, however, it seems that the range of the air circuit breaker can be extended considerably, both as to current and voltage.

Oil circuit breakers are the principal present day switching devices that are capable of opening currents of large magnitude at rated voltage. They are made in sizes ranging from a few amperes to units which will break a million and a half kv-a. and up to voltages as high as 220,000 v.

All of these switching devices are designed to open the circuits on which they are installed under load. For purposes of isolation, that is, say, to isolate an oil circuit breaker so that it can be overhauled, disconnecting switches are used. These as a rule are simply knife blade switches operated by a "hook-stick." Multiple disconnecting switches are also available, these usually being remote controlled through mechanical systems of bell cranks, rods and handles. Ordinarily disconnecting switches are not used to open power, although if suitable

arcing horns are provided, small amounts of charging current for a short length of high tension transmission line or the charging current of transformers of moderate capacity can be handled.

A special type of switch used on switchboards is the plug switch. These materially simplify the control of potential circuits and the synchronizing system of a.c. boards by making it possible to locate the receptacles in the immediate vicinity of the controlling and indicating devices of their respective circuits and by avoiding the grouping of a large number of leads in a small space. Potential plug switches such as shown in Fig. 1 are used to connect a voltmeter to any one of a number of generator or battery circuits, or to any phase of a polyphase circuit. Synchronizing plug switches are used for connecting a synchronism indicator or synchronizing lamps to the circuits which are to be synchronized. They are made so that incorrect connections cannot be made.

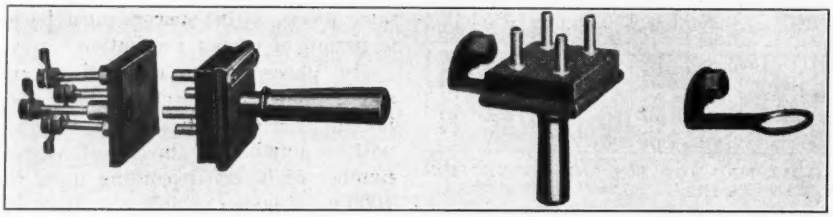


FIG. 1. SYNCHRONIZING AND POTENTIAL PLUGS WITH RECEPTACLES AND HOLDER

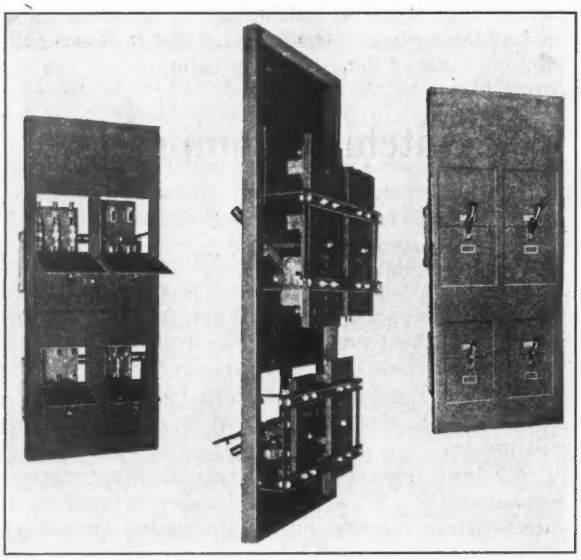


FIG. 2. BACK OF BOARD TYPE OF KNIFE SWITCH FOR USE IN INDUSTRIAL INSTALLATIONS

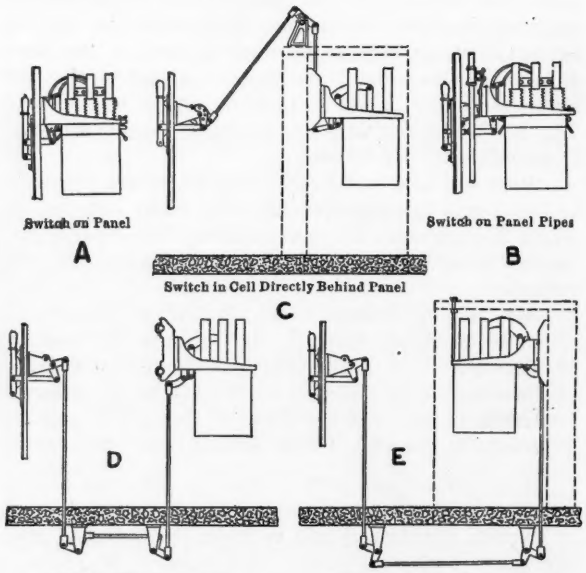


FIG. 3. METHODS OF MOUNTING SMALL OIL SWITCHES

Air Break Switches

Air break switches, used on direct-current and low-voltage a.c. circuits are of two kinds, the open knife blade type and the safety enclosed type. The open knife switch, today is used practically only on switchboard panels, where they are subject to the care of experienced operators and where their use is not necessarily a source of danger. In all other places, and this applies to the small individual panels used in factories for the control of motors, the air break switch should be of the safety enclosed type.

Open lever switches are installed directly upon the switchboard panels. They are made usually for use on voltages up to 600 and in capacities as high as 6000 amp. Switch contacts should be kept in adjustment at all times to insure that they will carry their rated load at all times. Adjustment, if found necessary, should be made in the following manner. Proper contact is obtained at the contact tongue when the laminated blades bear uniformly on all points of the tongue within the contact area. When the blade elements are assembled, the blades are parallel to one another. The blades should be curved inward slightly. This is accomplished by placing a steel rod between the blades and against the end of the holding screw, and delivering one or two hammer blows to the sides of the blades through a block of wood or hard fiber. The rod used should have a diameter approximately equal to the blade thickness. Contact surfaces should be coated with vaseline before testing for adjustment. This will prevent undue wear on the parts during adjustment. The switch blades should then be moved until the tongue is inserted between the blades, and the surface tested for contact with a 0.002-in. thickness gage at all points which can be reached. If good contact is obtained at the front of the blades and the thickness gage can be inserted at the back, the blades should be withdrawn and the operation repeated.

For installation in industrial plants, the back of board type of knife switch shown in Fig. 2 is becoming popular. This type of switch provides a maximum degree of safety. Doors of the fuse compartments are interlocked with the switch handles, that is, the switch must be in a full open position before the fuse door can be opened and the switch cannot be closed while the door is open.

Air Circuit Breakers

Air circuit breakers have a definite field of application, in direct-current service, and to a certain extent in a.c. service. They are built for use on direct-current circuits as high as 1500 v. and for capacities up to around 16,000 amp. although under test conditions such breakers have successfully opened circuits of 190,000 to 200,000 amp. They are built either as single, double or triple-pole units. In industrial service, caution must be exercised in maintaining the contacts in good condition and that they are not installed in such places as cement or flour mills, plaster or furniture factories or in any industry where acid or excessive dust and dirt are present. For service in such places oil circuit breakers are more suitable.

For use in industrial plants, the safety enclosed type of air circuit breaker is used to a considerable extent. While these are intended largely for individual installation on motor circuits, groups of such breakers are often centralized on one switchboard panel.

Oil Circuit Breakers

Oil circuit breakers are used generally for interrupting current at all voltages above 600. For panel mounting, as well as for wall and framework mounting behind the switchboard, oil circuit breakers usually have their poles enclosed in a common grounded rectangular oil filled tank which is removable by dropping it away from the contacts.

When the oil switch is supported on the rear of the panel, it is customary not to go over 2300 v. or 3000 kv-a. capacity. The reason for this limitation lies in the danger to attendants from high-voltage apparatus when in close proximity to low-voltage control and instrument wiring which necessarily is located on the rear of the panel and which requires periodic inspection. Where voltages higher than 2300 v. are to be dealt with, the wall or framework mounting shown in Fig. 3 is much more safe and satisfactory and this type of mounting is urged even for 2300-v. service. This type of mounting may be operated either by the use of the remote manual system or by electrical control but the former is most generally used. With this arrangement the back of the board is free from high-voltage apparatus and only the instrument wiring and exciter connections are to be taken care of. The additional expense of this arrangement is relatively slight—usually not over 10 or 15 per cent over that for the direct control, rear of panel mounting.

There are, of course, any number of different ways of mounting oil circuit breakers in accordance with these two methods and the actual arrangement used at any particular place depends largely upon local conditions. It is often convenient for instance to locate the breaker proper in the basement or floor below (or above) the floor on which the panels are mounted. In this case the control rods merely extend through holes in the floor, or the breakers may be operated electrically.

The control mechanism which is used to the practical exclusion of all others for switches and circuit breakers consists of a series of levers and rods. Changes in the direction of the operating force are made by means of short levers rotating on a fixed fulcrum commonly known as bell cranks. The connecting rods are commonly made of ¾-in. gas pipe as it is cheap, usually easy to obtain and is well suited to the purpose. Wooden rods are used for field and disconnecting switches.

Methods of Voltage Control

Rheostats and Mounting; Autotransformers, Automatic Voltage Regulators

CONTROL OF VOLTAGE of generators is usually accomplished from the switchboard by means of the field rheostat. There are different arrangements for operating rheostats dependent upon the particular

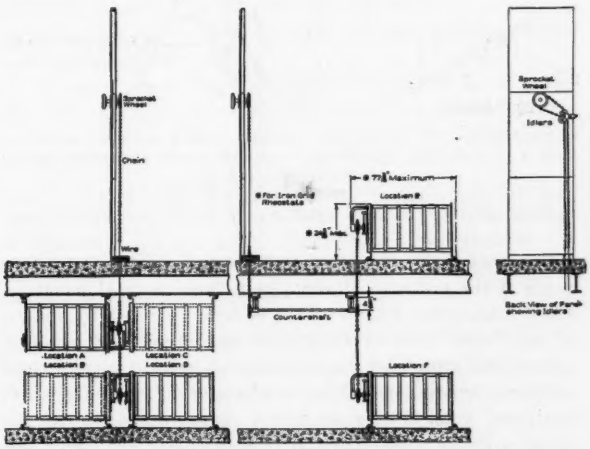


FIG. 1. POSSIBLE LOCATIONS OF RHEOSTATS

apparatus with which the equipment is to be used. Exciter rheostats are usually operated by means of a handwheel on the front of the switchboard, connected to the rheostat. For generators up to certain capacities the handwheels for the operation of the exciter and generator rheostats are made concentric, the generator rheostat being mounted in a convenient location and operated by means of a chain and sprocket. Generators of the larger capacities generally have motor-operated rheostats in which the control of the motor operating the rheostat is a single-pole, double-throw switch which is mounted upon the switchboard panels.

When rheostats are electrically operated, they may be placed where space is most conveniently available, but where they are operated mechanically through sprocket chains, the rheostat must be located somewhere near the board. In Fig. 1 are shown a number of possible arrangements. In any case, it is of course necessary that the rheostat and its mechanism shall not interfere with cable leads or switchboard apparatus and that the countershaft, if required, will not exceed six feet in length.

Auto-transformers are used frequently in connection

with switchboard devices to obtain voltages differing from the normal displacement of the circuit. For instance, in synchronizing across a power transformer bank connected Y—Δ the 30-deg. displacement of the line voltages must be rectified at the synchronizer. This is accomplished as shown in Fig. 2. In this figure the voltages 1′—2′ and 1—2 are normally 30 deg. displaced in phase when the systems are in synchronism. To overcome this displacement at the synchronizing device a small auto-transformer is connected across, say 1—3, on the delta side. This auto-transformer is equipped with a middle tap A and the synchronizer is energized from the voltage 1′—2′ on the Y side and A-2 on the Δ side, both of which voltages are in parallel when the systems are in synchronism.

When a polyphase wattmeter is used to measure re-

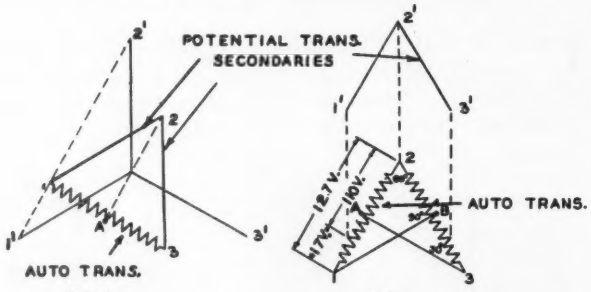


FIG. 2 FIG. 3

FIG. 2. DIAGRAM SHOWING USE OF AUTO TRANSPORMER IN SYNCHRONIZING

FIG. 3. DIAGRAM SHOWING USE OF TWO AUTO-TRANSFORMERS WITH REACTIVE VOLT-AMPERE INDICATOR

active volt amperes, it is necessary to shift the phase angle of the voltages 90 deg. from their normal positions when measuring watts. This is accomplished by means of two small auto-transformers mounted in a common case. The auto-transformers are wound to give a total potential across the entire winding of 127 v. They are equipped with a tap at 110 v. for connection to the secondaries of the potential transformers and with another tap at 63.5 v. to supply the quadrature voltages A-3 and B-1 for the reactive volt-ampere meter. These voltages A-3 and B-1 are 90 deg. displaced from the normal voltages 1′—2′ and 2′—3 respectively, and if the potentials 1′—2′ and 2′—3′ are 110 v. the potentials A-3 and B-1 are also 110 v., that is 127 cos 30 deg.

Automatic Voltage Regulators

While manual control of the field rheostats is useful in varying the voltage of generators over a comparatively wide range, most generating stations of any consequence today employ the automatic voltage regulator. These regulators are designed for installation on the switchboard panels and while they vary somewhat in design according to the size of generators and the particular method of application, in general the principles upon which they operate are the same.

The principle upon which nearly all of these voltage regulators operate is that of rapidly opening and closing a shunt circuit across the exciter rheostat, thus varying the exciter voltage in order to maintain the desired alternating voltage. A simple diagram of a regulator is shown in Fig. 4. It consists mainly of a d.c. control magnet and a relay magnet connected across the exciter mains and an a.c. control magnet, the latter provided with two windings, one a potential winding connected directly across the a.c. mains and the other a compensating winding connected to a current transformer. The relay magnet has a differential winding the lower one of which is connected directly across the exciter mains while the upper one is connected across the mains through the main contacts. The contacts on the relay short circuit the exciter field rheostat.

At any constant load, speed, and power factor, the a.c. magnet core does not actually move, the regulator acting as a d.c. regulator maintaining the proper voltage on the exciter to give correct alternating current voltage. With change in a.c. voltage the a.c. core will drop slightly. This forces the lower main contacts against the upper main contacts, which in turn closes the relay contacts. This causes the exciter voltage to increase. The travel of the a.c. magnet core will continue until the exciter voltage has reached a value corresponding to that required to give normal a.c. voltage under the new conditions of load or power factor. The d.c. side of the regulator will then operate and maintain the exciter voltage of the regulator at this high value in order to hold again the proper alternating current voltage.

With small machines, several exciters and generators may be controlled from one regulator. It is becoming

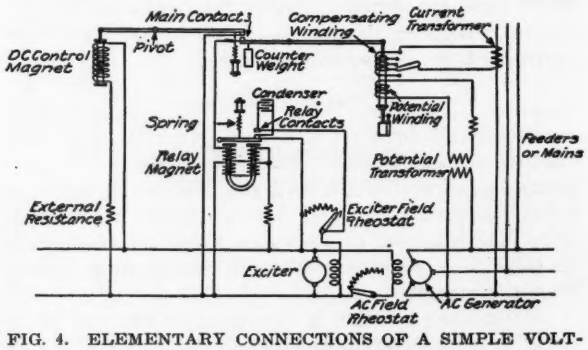


FIG. 4. ELEMENTARY CONNECTIONS OF A SIMPLE VOLTAGE REGULATOR

common practice, however, especially for larger generators with direct-connected exciters, to use an individual regulator for each generator. An equalizer rheostat in each exciter field and not short-circuited by the regulator gives one means of holding uniform loads on the two or more generators in parallel. The latest method, however, where individual exciters are provided, is to connect a current transformer 90 deg. out of phase to the potential used so that any circulating or exchange currents between generators will affect the compensating winding and result in adjustment for proper division of loads.

For a single generator, or for several small generators and exciters the voltage regulator may be mounted on brackets at the end of the board but where individual units are involved the regulators are more conveniently mounted on panels. In the smaller sizes two may be mounted one above the other on one panel within reach for adjustment, but in the larger sizes a complete panel for each regulator is usually required.

Although theoretically a two-cycle engine should develop twice the power of a similar sized four-cycle engine, the ratio is actually from 1.4 to 1.6 as much.

Switchboard Instruments

INSTRUMENTS FOR MEASUREMENT OF VOLTAGE, CURRENT, POWER, ETC. INSTRUMENTS FOR VARIOUS TYPES OF PANELS

INSTRUMENTS USUALLY provided on switchboard installations include those for the measurement of voltage, current, power, frequency temperature and power factor and for synchronizing and testing. The selection of the proper meters and instruments, however, depends to a certain extent upon the class of board used, the number of lines controlled, etc. In general, a careful selection of suitable meters is of more importance on the larger boards, especially the electrically operated, than on smaller ones, as more economies can be introduced in the operation of a larger station by skilled operators with suitable meter equipment, than would be possible in a smaller plant. On any class of board, a multiplicity of meters is to be avoided—only those which give necessary information should be used.

The selection of instruments is also dependent upon the use made of the electrical output, and to what extent it is necessary to guard against service interruptions. A small station, for example, which is maintained by an industrial plant and whose entire output is used on the manufacturing processes, seldom requires more than enough instruments to assure safe operation. Thus an ammeter for each generator and a voltmeter which may be connected to any generator circuit by means of receptacles and plugs with a second voltmeter for permanent connection to the bus bars are commonly used. Synchronizing may be accomplished by the use of lamps only. The indicating synchroscope is of considerable convenience and serves the purpose better than lamps but where first cost is of importance, lamps will do. Feeder circuits usually do not require meters but when a record of the distribution of energy is desired for accounting purposes, they are of great value.

Another factor which greatly influences the character of switchboard instruments used is the kind of attendant in charge of the board. Instruments that are not used or kept in calibration are worse than no instruments at all, as they only take up space, give no return on the investment, confuse the operator and complicate the wiring. The more simple the equipment throughout an installation the better the results obtained.

On three-phase circuits it is necessary, of course, to measure the voltage and current in each of the three phases. This may be accomplished by the use of three separate meters but is more often done with only a single meter together with the use of jacks or switches. Ammeter jacks are used to check the current on various phases. A recent improvement is the triplex ammeter, with a distinct saving in space over three separate ammeters.

The ammeter shows that part of the load responsible for the heating of the windings of the generators while the wattmeter shows the mechanical load imposed on the engine or turbine. As far as the electrical equipment is concerned, therefore, the ammeters are of greater importance than the indicating wattmeter, for it is the heating of the windings which fixes the load limits of the machine.

For determining the temperature rise in generating equipment, a temperature indicating meter is extremely useful. A common form of this is a direct-current instrument having two windings balanced against each other, one winding in series with a standard resistor and the other winding in series with a resistance detector coil embedded in the generator winding slots. This is ordinarily available only for larger machines. With increase in temperature the resistance of the detector coil increases while the standard resistor remains unchanged, and the amount of unbalance on the instrument is calibrated in deg. C. A number of detector coils are usually installed in each generator, but it is generally considered sufficient to connect three of these to the switchboard where they may be switched in turn to the one temperature meter.

In addition to the indicating wattmeter used to determine the load on the prime mover, watthour meters are also necessary to furnish a record of the total power turned out.

While instrument equipments will vary according to individual conditions, in general, certain combinations of instruments are necessary for certain type circuits. In the following we will present briefly, the instruments necessary for various circuits.

ALTERNATING CURRENT GENERATOR CIRCUITS

1 a.c. ammeter for balanced load. (When the load is unbalanced provision should be made for reading current in all phases, as above described.)
1 a.c. voltmeter. (Omit if a common or machine voltmeter is used.)
1 d.c. ammeter for the a.c. generator field. (Optional but desirable.)
1 Indicating wattmeter. (Optional.)
1 Power factor meter. (Optional.)
1 Frequency meter. (Optional.)
1 Synchronism indicator. (Not required for single generator station which will never operate in parallel with other machines or an outside source.) Lamps may be employed for this purpose instead of a synchroscope.
1 Temperature indicator. (Optional.)

Ammeters have already been discussed, so require no further comment here. The voltage readings are usually taken by means of the machine voltmeter common to all generators. This voltmeter is generally mounted on a swinging bracket or panel at the end of the board and is wired to all of the generator voltmeter switches. Many operators require a second or station voltmeter mounted on the same bracket with the machine voltmeter and connected permanently to the synchronizing phase of the bus bars. This instrument permits the simultaneous comparison of the bus bar and incoming machine voltage when synchronizing and should invariably be

specified as part of the switchboard instrument equipment.

When two or more generators are connected in parallel, field ammeters are almost indispensable. Incorrect field excitation for a given energy load means excessive or out of phase current in the generator or armature circuits.

In the operation of alternating current generators in parallel, the division of load is determined not by the field excitation but by the adjustment of the prime mover governor. For each position of the prime mover there is a corresponding amount of exciting current required in the generator field circuit to maintain proper voltage.

Indicating wattmeters give the instantaneous true energy output of the generator at all times, and greatly facilitate the efforts of the operator in maintaining proper energy load divisions between machines operating in parallel. This energy load cannot be determined by means of an ammeter and voltmeter, as they do not take into account the power factor of the load.

In many instances instead of a power factor meter, use is made of a reactive kv-a. meter. This instrument is nothing more or less than a standard indicating wattmeter so connected as to read the idle or wattless volt-amperes flowing in the circuit. The use of this instrument in some respects has preference over a power factor meter as it gives the direct reading of the idle volt-amperes circulating in the generator circuit.

The power factor meter is used principally to obtain without calculation, the instantaneous power factor of the generator circuit. In some cases, instead of using an indicating wattmeter, the energy is calculated from simultaneous readings of the voltmeter, ammeter and power factor meter.

Frequency meters, of course, give the instantaneous indications of the frequency of the generator and thus of the speed of the prime mover. In large stations it is usual to install one on each generator panel as it serves to indicate the frequency of the incoming machine when synchronizing. In general, however, a single instrument is provided on a swinging bracket and this may be connected to any generator circuit by means of a switch or plug and receptacle.

Feeder Panels for Motor or Power Circuits

For feeder panels for motor or power circuits, the only instruments usually provided are:

1 a.c. ammeter. (Alternates—ammeter switch or one ammeter per phase.)
1 Power factor meter. (Optional.)
1 Watthour meter. (Optional.)

One ammeter as a rule is sufficient and in some cases it may even be dispensed with. The power factor meter, however, is of greater importance, as poor power factor on one feeder circuit will lower the power factor of the entire plant and it is highly essential that means be provided for determining it. Where a large number of feeders are installed, one power factor meter is sufficient, means being provided to connect it to any feeder. The use of the watthour meter is optional, its use depending on whether or not records are needed for accounting purposes.

Synchronous Motor Panels

Synchronous motor panels require the following instruments:

1 a.c. ammeter.
1 d.c. field ammeter.
1 Indicating wattmeter. (Optional.)
1 Power factor meter. (Optional.)

Since the current in each of the three phases to a synchronous motor should be equal, only one ammeter is necessary. The d.c. field ammeter is of considerable importance since it enables the proper adjustment of field current to be made to meet the desired conditions. The indicating wattmeter and power factor meter, here, as in the case of the generator panel, will assist the operator to adjust the field properly so that the motor will take its proper share of the load. An indicating wattmeter when connected properly by means of a suitable switching device to its voltage transformers will read true watts with the switch thrown one way and the wattless volt-amperes when thrown the other way.

Load Totalizing Panels

For the purpose of indicating the total station output, a load totalizing panel is often provided, particularly where all the generating panels are at one end and all the feeder panels at the other. The instrument equipment provided on such panels will vary, of course, with the size and character of the station but as a rule will include a totalizing watthour meter (integrating or recording) an ammeter, an indicating wattmeter and a frequency meter. Sometimes a static ground detector is mounted on this panel and if space permits, the generator voltage regulator panel is mounted on it.

Synchronous Condenser Panel

The instrument equipment for a synchronous condenser is quite similar to that required for synchronous motors and usually includes an a.c. ammeter, a d.c. field ammeter, and a wattless indicating reactive volt-ampere meter. In this case the field ammeter and the armature ammeter are absolutely essential. It is desirable also to have the wattless kv-a. meter provided with a zero center scale so as to indicate promptly whether the condenser is furnishing leading or lagging wattless kv-a. to the system.

Frequently synchronous condenser panels are provided with automatic vibrating type voltage regulators which automatically vary the field excitation to the synchronous condenser so as to draw the proper leading current through the transmission line in order to hold a given voltage on the substation bus.

In 1860 the Lenoir engine, built by a Frenchman of that name, was built and is generally conceded to be the first commercial internal combustion engine, although the Stirling hot air engine, which is really an external combustion design, had been in service since 1816. In the Lenoir engine the charge was drawn in the cylinder and ignited at about mid stroke. With no compression, the efficiency was found to be low. In spite of its somewhat superior mechanical operation, it was short-lived, as it could not compete in economy with the Otto and Langen free piston engine developed in 1867.

General Principles of Transformer Action

DISCUSSION OF INDUCTIVE RELATIONS, VOLTAGE AND CURRENT RATIOS
EFFECTS OF RESISTANCE, LOSSES, FREQUENCY TRANSFORMATION

TRANSFORMERS are a form of stationary induction apparatus by means of which alternating electric energy applied to one winding called the primary winding, is transformed to alternating electric energy of the same frequency in another winding called the secondary but at a higher or lower voltage than that of the primary. The transformer consists fundamentally of two separate and distinct coils of wire insulated from each other and wound on a laminated iron core. When

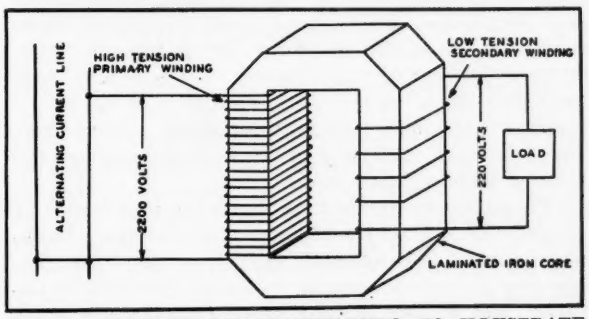


FIG. 1. ELEMENTARY TRANSFORMER TO ILLUSTRATE PRINCIPLE

the transformer delivers energy from the secondary at a voltage lower than that of the primary it is a step-down transformer; when it delivers at a higher voltage than that of the primary it is a step-up transformer.

In the secondary an alternating electromotive force is produced by reversals of the magnetic flux through the stationary iron core, these reversals being produced by alternating current supplied to the primary of the transformer. When the secondary is on open circuit, only a small current flows through the primary coil, thus inducing electromotive forces in both coils, that in the primary being opposite to the electromotive force applied and nearly equal to it. This difference permits a small current, called the no-load current of the transformer to flow in the primary.

The reversals of flux in the core always induce an electromotive force in the secondary, whether current is being drawn from it or not. The action of the secondary current when the transformer is supplying load, is to oppose the magnetizing action of the slight current already flowing in the primary coil, thus decreasing the maximum value reached by the alternating magnetic flux in the core and thereby decreasing the induced electromotive forces in both coils. This decrease is small, however, and the net result is that the flux in the core must be maintained approximately constant by the primary current whatever value the secondary current may have.

LOSSES IN ACTUAL TRANSFORMERS

Actual transformers have resistance and flux leakage and a certain magnetomotive force is required to force the flux through the transformer core. All these factors cause losses that tend to reduce the efficiency of transformation. Even so, the transformer is highly efficient, this efficiency in large units being as much as 98 per cent.

In an ideal transformer, the electromotive forces are in the ratio of the number of turns of wire in the respective coils. This ratio is called the ratio of transformation. A well designed commercial transformer approaches this ideal closely but for some purposes it is necessary to consider eddy currents, magnetic leakage and hysteresis. In general, however, the ratio of transformation can be considered to be $n_1 \div n_2$ where n_1 and n_2 are the number of turns of wire in primary and secondary coils respectively.

An auto-transformer has a single continuous winding used for both the impressed and one or more output voltages. If part of the primary winding is used for the secondary as in Fig. 2, the primary and secondary currents will both flow in that part of the winding between points a and b. As these currents tend to flow in opposite directions, the actual currents will be the difference between them. Furthermore I_2 being larger

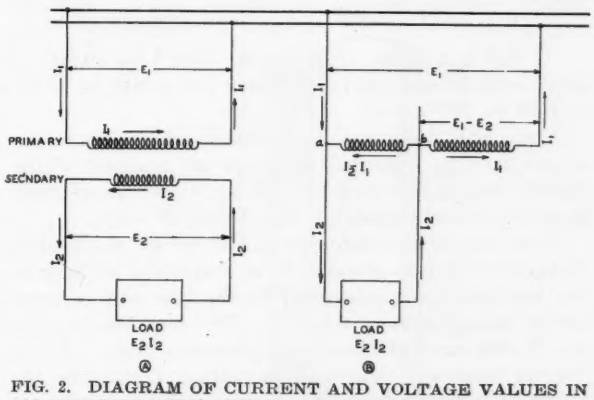


FIG. 2. DIAGRAM OF CURRENT AND VOLTAGE VALUES IN (A) TRANSFORMER AND (B) AUTOTRANSFORMER UNDER SAME OPERATING CONDITIONS

the direction of the resultant $I_2 - I_1$ will be in the direction of I_2. In the case of the auto-transformer although the same amount of power is furnished to the load, the current that actually flows in the winding is less than in a regular transformer. Less copper is needed therefore and less iron.

IRON AND COPPER LOSSES

Transformers are subject to both iron losses and copper losses. The copper losses which produce heat, are the resistance loss, I^2R and a small-eddy current loss, due to the leakage magnetic flux passing through the conductors.

The I^2R loss is usually specified at normal rated load and a definite temperature. The current used in calculating this loss is the watt rating of the transformer

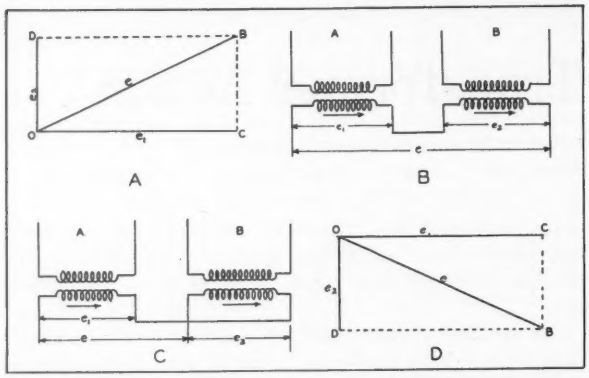


FIG. 3. DIAGRAM ILLUSTRATING PHASE TRANSFORMATION

As shown at B, the secondaries in series will differ in phase by 90 deg. if their primaries are connected to a two-phase system. Then the e.m.f.s of the two secondaries will be their vector sums as at A. If one secondary is reversed as at C. the resultant voltage will be reversed, hence a single-phase current can be obtained of any desired phase relation from two currents differing in phase by 90 deg.

divided by the voltage of the particular winding involved.

If R_1 and R_2 are the resistances of the high and low-voltage windings respectively, and r the ratio of high to low voltage, the equivalent resistance R would be:

$$R = R_1 + r^2 R_2$$

If a 2200 to 220-v. transformer has a primary resistance of 0.43 ohms and a secondary resistance of 0.0055 ohms then

$$R = 0.43 + (10^2 \times 0.0055) = 0.98 \text{ ohms}$$

If this is a 50-kw. transformer, then $I = 50{,}000 \div 2200 = 22.75$ amp. and the copper loss would be $22.75^2 \times 0.98 = 506$ watts.

Ordinarily in operation the eddy-current loss in the copper may be neglected, although the designer of the transformer must consider it. For a 50-kw. transformer as above it would probably be not over 20 watts.

Iron loss in a transformer is the energy required to magnetize the iron circuit. It is continuous as long as the transformer is connected to the line and is practically independent of the load. This iron loss is made up of eddy-current losses and hysteresis losses. Eddy-current losses are caused by currents, generated by the alternating flux, circulating within each lamination of the core. They are minimized by using thin laminations and by insulating laminations with a non-conducting

TABLE OF EFFICIENCY AND REGULATION OF 2200/220/110-V. DISTRIBUTION TRANSFORMERS

Kva.	Watts loss		Per cent efficiency				Per cent regulation				Per cent exciting current
	Iron	Copper	Full Load	½ load	¼ load	⅛ load	100% P.F.	90% P.F.	80% P.F.	70% P.F.	
½	15	15	94.7	94.4	93.2	88.8	2.6	2.73	2.62	2.5	6.0
1	20	24	95.8	95.7	95.0	92.0	2.4	2.51	2.41	2.25	5.5
1½	24	33	96.4	96.4	95.8	93.5	2.2	2.4	2.35	2.3	4.0
2	29	40	96.7	96.7	96.2	94.1	2.0	2.25	2.23	2.2	3.6
2½	32	51	96.8	96.9	96.5	94.7	2.05	2.42	2.45	2.4	3.5
3	33	57	97.1	97.2	96.9	95.4	1.92	2.31	2.38	2.35	3.0
4	37	70	97.4	97.5	97.4	96.0	1.81	2.55	2.75	2.65	1.9
5	45	82	97.5	97.6	97.5	96.3	1.7	2.35	2.51	2.6	1.8
7½	57	110	97.8	97.9	97.7	96.7	1.55	2.4	2.6	2.8	1.7
10	70	140	97.9	98.0	97.9	96.9	1.47	2.32	2.6	2.7	1.65
15	95	192	98.1	98.2	98.1	97.2	1.35	2.2	2.42	2.58	1.5
20	123	255	98.1	98.2	98.1	97.3	1.35	2.6	3.0	3.25	1.3
25	158	305	98.2	98.3	98.3	97.5	1.3	2.6	3.0	3.3	1.25
30	158	370	98.3	98.4	98.3	97.6	1.29	2.75	3.2	3.5	1.15
37½	175	415	98.4	98.5	98.5	97.9	1.18	2.9	3.45	3.8	1.05
50	239	520	98.5	98.6	98.5	97.8	1.14	2.7	3.22	3.57	1.0

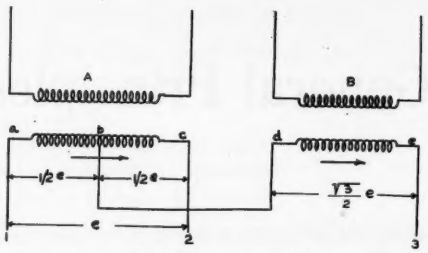


FIG. 4. SCOTT TRANSFORMER CONNECTION FOR CHANGING FROM 2-PHASE TO 3-PHASE

coating. Hysteresis losses are due to the power required to reverse the magnetism of the iron core at each alternation.

Efficiency of Units

Transformer efficiency is the ratio of the output to input, or of the output to the output plus the copper and iron losses. The accompanying tabulation shows average values of efficiencies for 2200 to 220 and 110-v., 60-cycle distributing transformers. The table also shows the regulation of transformers; regulation is the rise of secondary terminal voltage from rated non-inductive load to no load, expressed in per cent of secondary terminal voltage at rated load.

Transformers may be used to effect a transformation of phase as well as transformation of voltage. Three-phase currents, for instance, may be converted into two-phase or vice-versa, three or two-phase into four or six-phase, and to any desired phase except single-phase. Various schemes have been proposed for converting polyphase to single phase but none gives better results than simply placing a single-phase transformer across one phase.

Fundamentals of Transformer Construction

Types of Cores and Windings, Leads, Casings, Methods of Mounting and Cooling

CLASSIFIED ACCORDING to their mechanical construction, transformers are divided into two types: shell type and core type. On the basis of cost, small high-voltage transformers are usually of the core type and large low-voltage units of the shell type. Classified according to use they consist of large and heavy duty transformers for power purposes and others used for distribution.

Cores for transformers are built up of a number of sheet iron or steel stampings, each lamination being treated with an insulating varnish. In some forms, the stampings may be rectangular, in others, L-shaped. Three and four-part cores are usually built up with L-shaped laminations assembled to secure a large center section with magnetic sections radiating at 120 deg. or 90 deg. as may be required.

Transformer Windings

Windings are either wound directly on the core or wound on forms and later assembled in the core. In the interleaved disk type of winding, both high and low-voltage coils are wound in the form of disks assembled with the high-voltage and low-voltage coils interleaved.

They are assembled over a cylinder and then over the core, the coils separated by spacers. In the disk-cylinder type of winding, the low-voltage coils are cylindrical in shape. The high-voltage windings are disk coils assembled over a cylinder, which is in turn assembled over the low-voltage winding with an oil duct between that winding and the outer cylinder. In the cylindrical construction, both high- and low-voltage coils are cylinders wound on forms and assembled concentrically with oil ducts between the coils.

Three styles of tanks for distribution transformers are used. Small units are assembled in smooth cast-iron

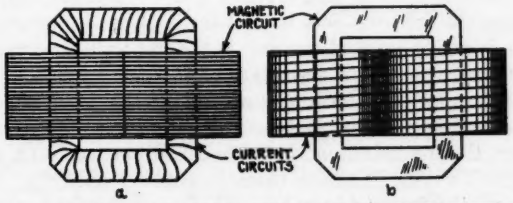


FIG. 1. SHELL AND CORE TYPES OF TRANSFORMERS

tanks. For pole suspension, these are often of welded steel to save weight. For larger sizes of welded tanks, corrugations are used to give increased radiating surface and strength. For distribution transformers too large for pole suspension, tanks are of corrugated sheet steel sides, cast-welded into cast-iron base and top rim. Tank covers usually have overhanging lips and a gasket between cover and tank to keep out dust and moisture.

For voltages below 20,000, transformers often have the leads brought out through bushings in the over-

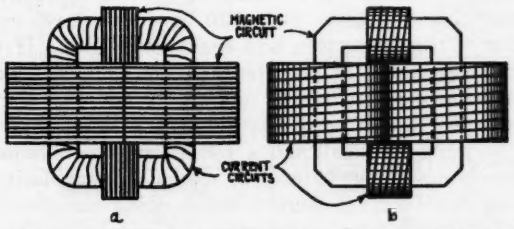


FIG. 2. DISTRIBUTED TYPES OF TRANSFORMERS

hanging pockets. Leads for higher voltages are brought out through non-puncture bushings in the cover of the transformer, the bushing made tight by a gasket.

Outlet terminals may be of the condenser type or the oil-filled type. The former consists of alternate layers of thin tin-foil and shellacked paper rolled hot on a central brass rod.

Oil-insulated terminals employ oil as the insulator. They consist of porcelain segments cemented together to serve as a container for oil with a conductor rod extending through this container. The oil space is subdivided by insulating cylinders to prevent lining up of particles in the oil into conducting paths.

Cooling Transformers

Methods used to remove heat in transformers are: 1, natural convection of air and radiation, used for small distribution and switchboard transformers; 2, forced circulation of air, as in air-blast transformers, which are built in all sizes and for voltage up to 35,000; 3, natural convection and radiation of two fluids, as in oil-insulated, air-cooled units built in sizes up to 8000 kv-a.; 4, combination of natural convection of a fluid with forced circulation of air; 5, natural convection of an insulating fluid which is artificially cooled by another fluid; 6, forced circulation of a fluid cooled in any convenient way.

On transformers cooled by free convection of air, the difference in temperature or weight of air at the bottom

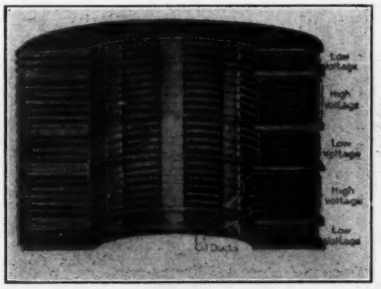


FIG. 4. INTERLEAVED TYPE OF TRANSFORMER COIL, WITH OIL DUCTS

and top of the coils furnishes the circulation. In oil-insulated, self-cooled types, the transformer is immersed in oil circulating by free convection, the oil being cooled by conduction through the casing. Air-blast transformers depend on free circulation of air forced under pressure through the transformer.

In some types of oil-immersed transformers, hot oil taken from the top of the coils is artificially cooled and returned to the bottom of the transformer casing.

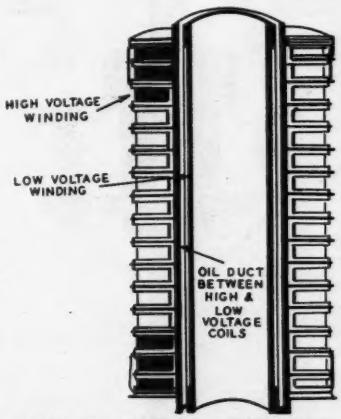


FIG. 5. DISK-CYLINDER TRANSFORMER COILS

Water-cooled transformers have a water circulating coil near the surface of the oil.

For forced oil circulation, the oil is circulated as well as artificially cooled. The banked radiator type of self-cooled transformer has banks of pipes or radiators on the outside of the shell through which the oil circulates under its natural sypho-thermal head.

Oil for Transformers

Transformer oil and other insulating oils that have deteriorated because of physical changes or presence of moisture, carbon or other foreign substances, may be reclaimed. Special oil filtering equipment is available for this, as well as centrifugal purifiers and other devices.

On large high-voltage transformers oil conservators

are often used to prevent moisture entering the main tank, to prevent sludging of oil and, by maintaining the transformer tank completely filled with oil, prevents the formation of an explosive mixture of oil vapor and air.

To overcome oxidation of oil in transformers, the inertaire transformer has been developed, in which all air is excluded and the space above the oil level is kept filled with an inert gas, mostly nitrogen. This body of nitrogen is automatically created by the controlled

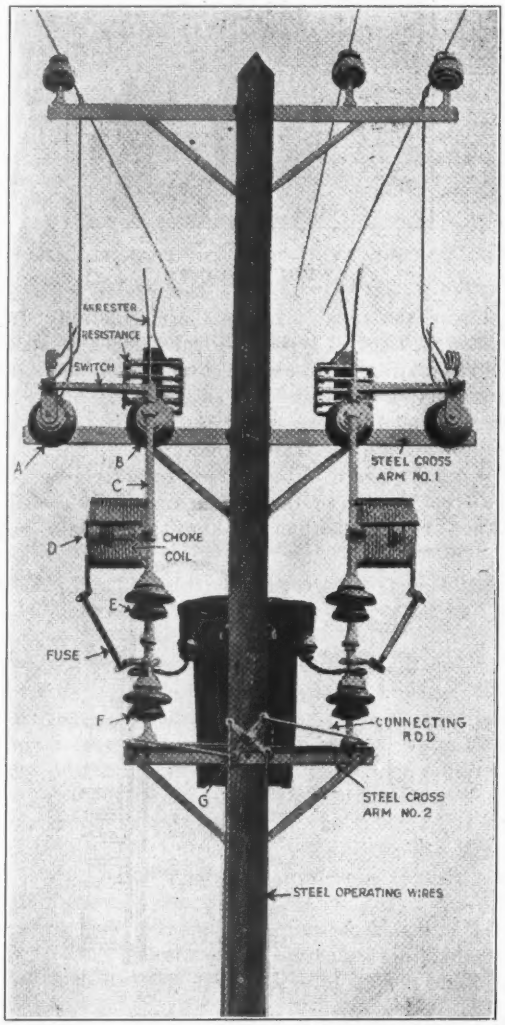


FIG. 6. POLE TYPE SUBSTATION FOR SMALL INDUSTRIAL INSTALLATIONS

natural breathing of the transformer, employing certain chemicals through which air is drawn.

The transformer tap-changing switch is a device for rapidly and conveniently varying the ratio of a transformer by changing tap connections. These switches are mounted under oil inside the transformer and are operated by a handwheel outside the cover, an insulated shaft being used, brought through the cover by suitable stuffing-boxes to prevent leakage. The handwheel has a pointer moving over a dial, on which numbers correspond to tap positions and a diagram indicates the voltages obtainable.

Systems of Transformer Connections

Internal and External Connections for Various Voltage and Current Combinations

FOR DIFFERENT purposes for which transformers are used there are definite methods of connection, sometimes several possible arrangements and the following brief outline discusses some of the most important of these as they apply to internal and external connections.

In Fig. 1 is a single-phase transformation and the nomenclature used here is used in the other illustrations. The winding marked "high" is the one with the greater number of turns, in accordance with the A.I.E.E. rules. The low winding terminals are marked X-1 and X-2.

For distribution systems having a third or neutral wire, the low winding is divided into halves, X-1A and X-2B. Figure 2 shows them in parallel and Fig. 3 in series, the latter being the ordinary three-wire system so widely used. Figure 4 shows the external arrangement of the low-side leads.

To compensate for voltage changes due to line drop, percentage taps are sometimes used as in Fig. 8. If the winding were in halves with taps, these would have to be equally placed on both sections to permit parallel operation as in Figs. 9 and 10.

Parallel Connections

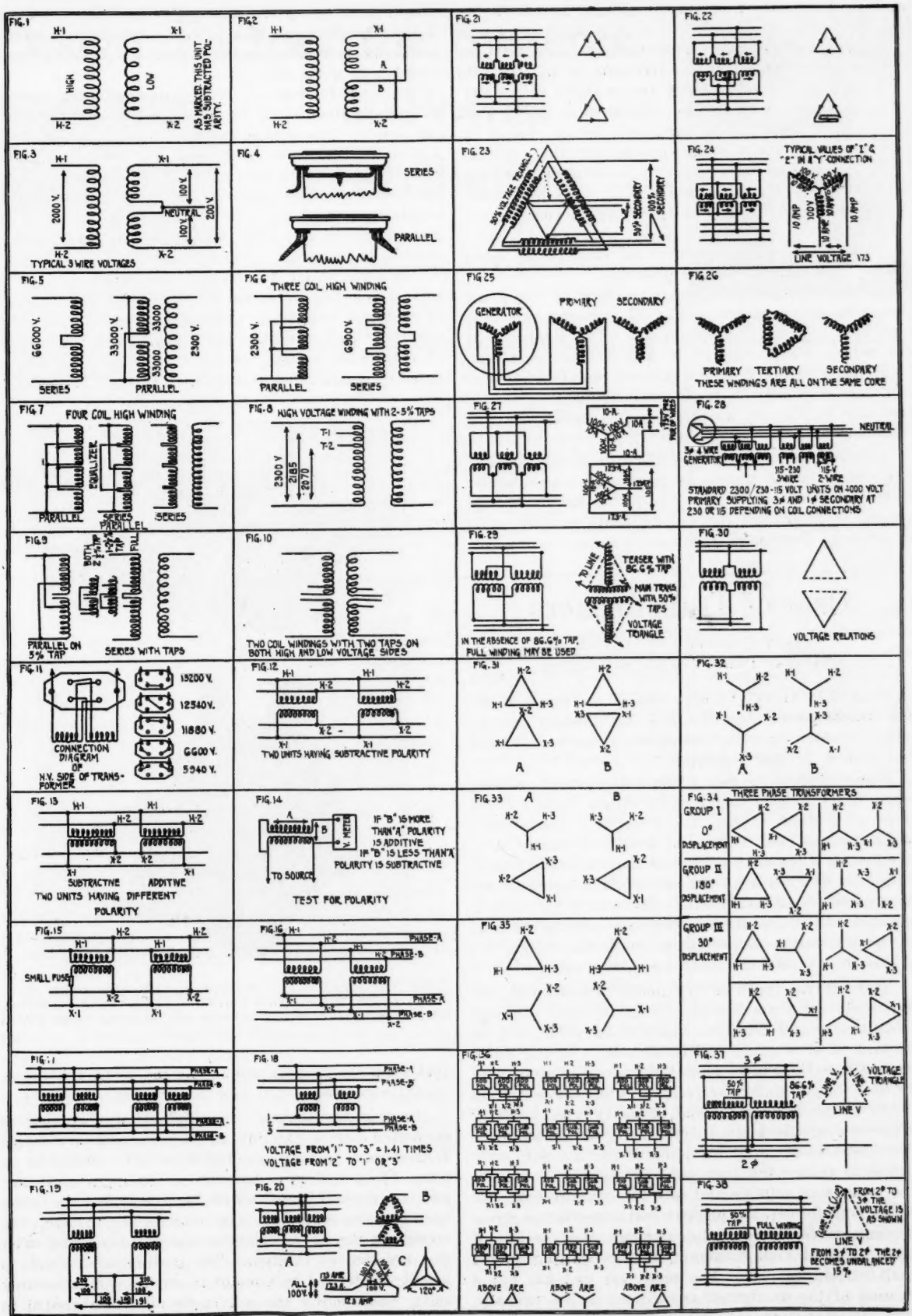
For utilizing apparatus on hand or providing for increased loads, transformers are often connected in parallel as in Fig. 12. To do this, the load must divide equally between them, therefore they must have equal ratios of transformation and equal impedance. If this is the case, then the only point to consider is polarity and the connections are as in Figs. 12 and 13. Figure 14 shows a method of testing polarity with a voltmeter. If the units are small and a voltmeter is not available, connections of Fig. 15 may be used. If the polarity is wrong the fuse will blow without doing any damage. Connections for two-phase operation are as in Fig. 16 and as shown in Fig. 17, the above rules for parallel operation also apply. Figure 18 shows how one wire in the secondary of a two-phase system may be eliminated.

Three-phase transformation using single-phase units connected in delta is shown in Fig. 20. A represents the actual way the connection would be made, B the same connection simplified and C the vector diagram. With balanced loads, each transformer carries only 1/1.73 of line current. In delta connection, the polarity of the units must first be determined. If they are all the same, a start-to-finish arrangement as in Fig. 21 may be made. If one has odd polarity, the connection is as in Fig. 22. To secure two secondary voltages from the same bank, the circuit of Fig. 23 is used.

Star-Star Connection

Figure 24 shows a star-star or Y-Y connection. Here the line current is the same as that of each unit but the line voltage under balanced conditions is 1.73 times that across each transformer.

A Y-delta connection is shown in Fig. 27, the relative values of currents and voltages being noted. This is



FIGS. 1-38. INTERNAL AND EXTERNAL CONNECTIONS OF VARIOUS TYPES OF TRANSFORMERS

used in four-wire, three-phase systems as shown in Fig. 28.

An extremely common connection, the open delta or V-V, uses two transformers arranged as in Fig. 30.

Figure 31 A and B show two possible delta-delta unit connections, with 180-deg. displacement at B. Two such groups could not be paralleled, for no change in external heads would change one to the other, the internal connections would have to be changed. In Fig. 32 A and B is a combination of Y-Y units that could not be paralleled without changing the internal connections.

Figure 36 shows a number of connections using single-phase units of various polarities.

The Scott connection for three-phase to two-phase transformation is shown in Fig. 37, utilizing two units connected T on the three-phase side. Two similar units are usually used, both with 50 and 86.6 per cent taps. Under emergency conditions, however, units with 50 per cent taps only may be used, resulting in the distorted condition of Fig. 38, which prevents parallel operation with true three- or two-phase circuits.

Single-phase power can be taken from any phase of a polyphase system merely by connecting a transformer across the proper pair of wires. This unbalances the system, however, and the various loads so taken must be properly distributed to balance it again.

Uses of Transformers

CONSTANT CURRENT AND VOLTAGE, INSTRUMENT TRANSFORMERS, REGULATORS

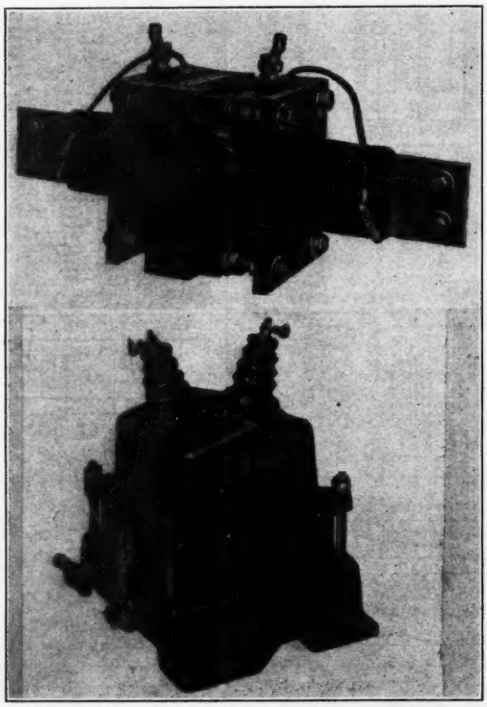
ACCORDING TO THEIR uses in the power plant, transformers are classified as constant voltage ratio, constant current, instrument, auto-transformer and feeder voltage regulator.

Some circuits require a constant current, notably series street lighting circuits; to supply these circuits from a constant voltage line requires a transformer which automatically varies the secondary voltage so as to maintain a constant current in the secondary circuit. Such a transformer is known as a constant-current transformer and is so constructed that one set of coils is movable with respect to the other, thus varying the ratio of transformation in accordance with the voltage required to maintain constant secondary current.

Two general types of instrument transformers are employed; these are known as current and potential transformers and differ in construction principally in the method of winding and insulation. Current transformers have their primary coils connected in series with the load. These coils, therefore, carry the whole current of the circuit and are wound of heavy wire, cable or strap copper, only a few turns usually being employed. Potential transformers are designed for use with voltmeters to reduce the high potential of a generator or line to a value suitable and safe for measurement. In such a transformer, the primary coil is connected across the line, as for voltage measurement, and consists of many turns of high resistance, thus permitting only a small current to flow. The secondary coil has but a fraction of the number of turns used in the primary, thus giving a terminal voltage which is suitable for measurement by an ordinary voltmeter. The terminals of the secondary coil of a potential transformer should not be short-circuited, as the current which would result would destroy the coil.

Autotransformers are used principally for cutting down the voltage of the line to a motor during the starting process. The general construction differs little from a power transformer except that the winding consists of a single coil with taps taken off at intervals. These taps lead to contact points in a starting box so that, by shifting a control lever, the voltage to the motor is increased step by step until the full line voltage is reached and the motor is up to speed.

On some feeder circuits the load varies greatly, resulting in a drop in voltage which disturbs the operation of electrical equipment depending upon that line for current. This condition has brought forth the design of the feeder voltage regulator which is essentially a specially constructed transformer having moving coils



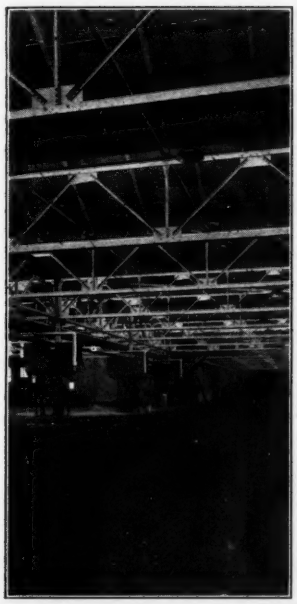
ABOVE, CURRENT TRANSFORMER FOR USE WITH CURRENT-MEASURING INSTRUMENTS. BELOW, POTENTIAL TRANSFORMER USED TO PROTECT VOLTMETERS FROM LINE VOLTAGE

that maintain constant voltage on the secondary circuit regardless of the load it may be carrying.

In this transformer, the high-voltage winding is connected across the line as with an ordinary transformer but is so constructed that it can be rotated on an axis. The secondary or low-voltage winding is stationary and is connected in series with the line so that the entire current flows through it. By rotating the primary, the voltage of the line is raised or lowered depending upon the direction of rotation. The position of the coil is usually controlled by a motor through a contact-making relay which moves the coil in the direction needed to give the required voltage.

Design Factors for Systems of Power Distribution

By Chancey S. Millard



FLOOR TYPE UNIT HEATERS TRENCH RETURNS

Chancey S. Millard, a native of Chicago, is a graduate of Armour Institute of Technology. First employed by the Chicago City Railway Company, as structural Engineer. In 1911, Structural Engineer in Architectural Dept. Canadian Pacific Railway Co., Montreal. During 1912 to 1916, Chief Engineer for Painter and Swales, Architects, Vancouver, B. C., in charge of mechanical and structural design for Canadian Pacific Railway Hotels, at Victoria, B. C., Vancouver, B. C., Lake Louise and Banff. From 1917 to 1918, Mechanical Engineer, Mills, Rhines, Bellman & Nordhoff, Architects, Toledo, Ohio. In 1918 he became associated with the Leonard Construction Co., Chicago, as mechanical engineer, continuing in this capacity until 1924. From 1924 to date, chief mechanical engineer for Frank D. Chase, Inc., Engineers and Architects, Chicago, Illinois.

STEAM, ELECTRICAL and mechanical power are distributed to such a large variety of industries and buildings of all types, whose individual requirements vary greatly, that each building, or group of buildings, is a separate problem which must be studied and the systems of steam and power distribution designed to meet the particular requirements of the case in question.

Heating

In the distribution of steam for heating, for production of power and for process purposes, the most important item is the heating system, as it is a part of nearly every building problem.

For either a single building or a large group, usually supplied with steam from a single boiler plant for economy in operation, the boiler plant should be located as near the center of distribution as is practicable, to reduce the cost of piping.

In its simplest form, with a low-pressure boiler plant where the extent of the system is rather small, a large number of buildings can be economically heated with steam at from 1 to 5 lb. pressure.

Unit heaters are the most common method for the manufacturing portion of the building, with cast-iron radiators in the offices, as this is more economical than the use of cast-iron radiation throughout and is cheaper in first cost. For buildings of one-story construction without a basement, it is necessary to run the low-pressure returns below the floor in tile pipe, or in covered concrete trenches, see headpiece, the latter being preferred on account of accessibility but being more costly.

Where a plant is spread out over a considerable area, the cost of large, low-pressure mains becomes excessive. With an extensive system of steam distribution, it becomes advantageous to install boilers operating at pressures from 100 to 125 lb. The boiler plant is generally housed in a separate building from which the high-pressure mains are carried to the various buildings, in the majority of cases, over-head on pole lines. This is the cheapest method in first cost but the losses are greater and the maintenance higher than for underground distribution. Underground steam lines are carried in insulated tile pipe in trenches and in concrete tunnels. A tunnel large enough to work in is an ideal arrangement but its cost is warranted only in the case of very large plants.

Where boiler pressure of 100 to 125 lb. is carried, it is advisable to reduce the steam pressure in each building to about 30 lb. for the unit heaters. While higher pressures can be carried on them, the resulting high temperature of the discharged air is inadvisable. The heat output of the unit heater becomes out of proportion to the volume of air handled by the fans, with the result that there is insufficient air change in the buildings.

With the use of steam at from 15 to 30 lb. it is possible to place the returns overhead, Fig. 1, lifting the condensate at each unit heater, which eliminates underground returns. Where distances to the boiler plant are moderate, the returns can be carried overhead to a condensation pump and receiver located in the boiler room. But, in some cases, it is advantageous to install a pump and receiver in the building to be heated, pumping the condensate to a receiver or hot well located in the boiler plant.

Many industries require the use of steam at from 10 to 100 lb. for process purposes, such as drying, cooking, heating liquids and the distillation of petroleum products. Pressure maintained on the boilers may depend upon the requirements for process steam. The process-steam piping system should be separated from the heat-

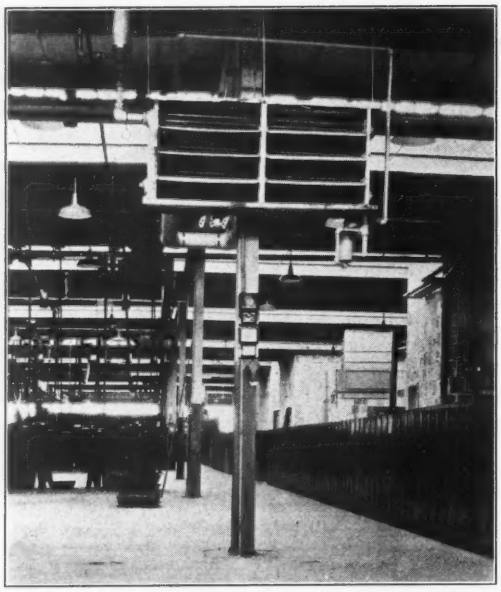


FIG. 1. SUSPENDED UNIT HEATERS FOR 30 LB. PRESSURE WITH OVERHEAD RETURNS AT SNAP ON TOOLS, INC. PLANT

ing system, even though the pressures are the same, as this permits the heating system mains to be shut off during summer months when only process steam is required. Process steam mains should be well insulated on account of their use in warm weather, when the radiation of heat is objectionable.

In one interesting installation, where large quantities of high-pressure steam are required for manufacturing purposes, a plant was built for steam at about 1200 lb. pressure. This was passed through a generating plant, the surplus energy being sold to a public service company, while the exhaust at the desired pressure was utilized in the plant. No doubt in many industries this method of steam production would prove equally successful.

For multi-story manufacturing plants, the heating system is similar to that for office buildings and hotels. It may be either up-feed or down-feed, an up-feed system being used in the majority of cases with mains located on the ceiling of the lowest story. The up-feed riser system is the cheapest in first cost and is to be recommended.

Location of overhead piping in any industrial plant requires careful consideration in order to provide the proper head room yet avoid interference with cranes, line shafting, conduit and other services and equipment. Long straight runs require expansion joints, which are most generally of the U bend type. Underground returns of great length should have sliding or bellows type expansion joints located in manholes.

Institutional Plants

In buildings of considerable height, the most common practice is the down-feed system with the mains located in an attic pipe space, as this arrangement gives small vertical feeders at the lower floors where concealment is of primary importance. In favor of the up-feed system, there is the lower cost and the elimination of mains at the top of the building, which have to be located in a pipe space or be exposed on the top floor. To conceal the top floor mains requires additional height of building.

In many institutional buildings the heating plant consists of an installation of high-pressure boilers, operating at from 100 to 125 lb. pressure, unless higher pressures are required for a complete power plant to generate electric power and light. Any live steam needed for the heating system is passed through a reducing valve into the heating mains.

It has proved economical in large hotels to install a generating plant on account of the large demands for exhaust steam for heating the large quantities of hot water needed for kitchens and bathrooms, in addition to the heating system requirements.

Large hospitals are often provided with a generating plant as institutions of this type frequently have their own laundries, requiring steam at 100 lb. pressure. An intermediate pressure system for supplying steam to the kitchens and sterilizers at about 30 lb. pressure is necessary, the heating system for the direct radiation and the heating coils of the ventilating system being supplied by exhaust steam or through a reducing valve.

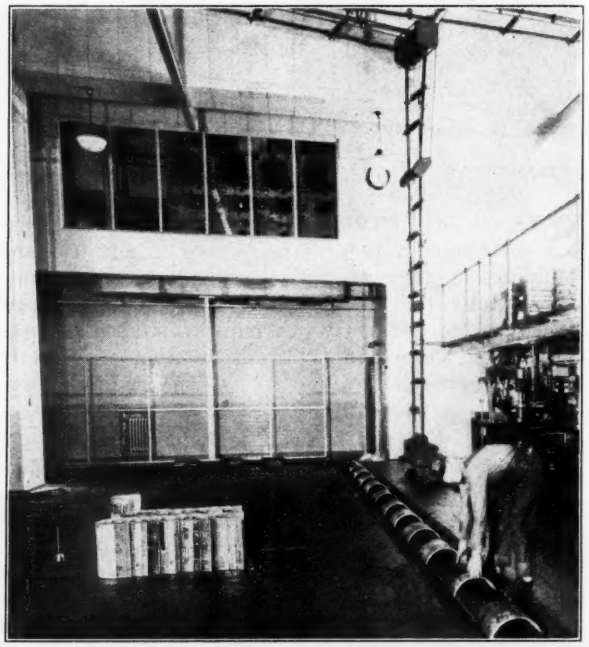


FIG. 2. PLATE CONVEYOR AND PRESS CONTROL GALLERY, OKLAHOMA PUBLISHING CO.

Office buildings are provided with high-pressure boilers in some cases and with low-pressure boilers in others. First cost is greater for the high-pressure installation which generally includes water-tube boilers and stokers, operating at higher efficiencies than the average low-pressure installation. Steam to the vacuum heating system is supplied through a reducing valve from the high-pressure plant.

In some cases it has been found profitable to provide a generating plant, selling steam and electric service to adjoining buildings.

Heat regulation is accomplished by automatically

controlling the amount of steam supplied to the radiators or by controlling the pressure on the system. The "differential" system is an example of the latter type, in which the pressure on the heating system is varied from a positive pressure to as much as 20 in., according to variations in weather conditions. A more or less constant pressure differential is maintained between the supply and the return mains. Such a system results in fuel saving and more comfortable temperatures.

Regulation by controlling the steam to the radiators has been used successfully for some time, either by a combined valve and thermostat mounted directly on each radiator or by valves on the radiators, pneumatically or electrically controlled from a room thermostat, mounted on the wall.

In many industrial plants, the fans on the unit heaters are controlled by thermostat, which reduces the condensation in the heaters and saves fuel.

Electric Distribution

Service commonly provided by the public service companies is 3-phase, 60-cycle, 220-v. for power and 110—220-v., single-phase for lighting. Considerable saving in copper can be realized if 440-v. power can be obtained.

Where direct-current service is provided direct-current motors have the advantage of wide speed variation with heavy torque. Such systems are high in first cost, due to large feeder requirements, expensive motors and control equipment and high maintenance cost. Some plants are served throughout by alternating current, except for large cranes which are operated with direct current obtained from motor-generator sets. Some engineers favor direct current for operating presses in large newspaper plants, Fig. 2, on account of the variations in speed required, the electrical losses being less in the case of direct current.

FIG. 3. CONTROL PANELS FOR INDIVIDUAL PRESS MOTORS, ROBERT O. LAW CO. SUSPENDED UNIT HEATERS USED

For transmission and general distribution of large amounts of electrical energy, polyphase systems are outstanding in superiority. Generally distribution is on the 3-phase system, with 4-wire primary at 2,300—4,000 v. and 3 wires for secondary distribution at 220 or 440 v.

Two-phase systems of 4 or 3 wires are also used somewhat, principally in older installations. About 33 per cent more copper is required for 2-phase than for 3-phase systems. With a 2-phase power installation, a single-phase, 3-wire lighting system should be provided, as a 2-phase system for lighting would require 220-v. lamps.

Three-phase, 4-wire systems are coming into use for combined power and lighting loads supplied from one transformer bank. Such a system furnishes 204-v., 3-phase, 3-wire service for power and 118-v., 3-phase, 4-wire service for lighting, which reduces the cost of copper for the lighting feeders.

Formerly, it was the practice to employ only 2-wire branch lighting circuits but 110—220-v., single-phase feeders from 3-wire branches are now being used, resulting in a saving in wire. For 4-wire, 3-phase lighting systems, 4-wire branch circuits may be used.

In some localities it is the practice in industrial plants to omit separate sets of feeders for the lighting system. Air-cooled transformers are mounted adjacent to each lighting panel and connected to the power feeders. This may result in poorer voltage regulation for the lamps but the first cost of the installation is appreciably less.

Mechanical Transmission

In the design of modern industrial plants, mechanical power transmission is limited to applications of line shaft drives for certain types of machines.

Today the tendency is toward individual motor drive, as far as practicable, Fig. 3. As most plants use induction motors, any investigation as to the type of drive for machinery and equipment must take into consideration the question of power factor. Machines can at times be driven more economically from a line shaft than with individual motors.

In general, if a machine has a fairly constant load, it is suited to individual motor drive, with the induction motor so selected that it will be running as close to full load as possible. Machines with a widely varying load are best operated from a line shaft to which a number of similar units are connected. Punch presses are an example of this type of equipment. They operate momentarily at maximum load and are idle during the intervals. If the line shaft motor driving the group is selected for the total average load, the power factor will be higher than if each machine has its own motor.

With induction motors it is important that the questions regarding mechanical and electrical drive be carefully considered, otherwise the plant may have a bad power factor, which must be corrected by a large synchronous motor, connected, possibly, to an air compressor or by a static condenser, since low power factor is costly, the service companies penalizing customers, if the power factor is below a certain figure.

Transmission of Power by Means of Shafting

PROPER SELECTION AND INSTALLATION OF SHAFTING AND ITS ACCESSORIES ARE ESSENTIAL TO SATISFACTORY OPERATION

SHAFTING transmits power through the torsional stress placed upon it, so that the material used has much to do with the successful application. In general, cold rolled steel has been found most satisfactory for power transmission purposes. Forged steel, because of its greater strength is recommended for line shafting above 6 in. in diameter and in special cases where strains are unusually severe, nickel and vanadium steels are finding application.

In the design of shafting for mill or factory work, the general formula for horsepower capacity is:

$$hp = \frac{D^3R}{C} \quad \text{or} \quad D = \sqrt[3]{\frac{C \times hp}{R}}$$

In which hp = allowable horsepower capacity.
D = diameter of shaft in inches.
R = speed of the shaft in revolutions per minute.
C = constant for allowed bending and twisting strain.

The constant of C depends upon the service to which the shaft is put and for cold rolled steel with a tensile strength of 40,000 to 50,000 lb. per sq. in. and an elastic limit of 25,000 lb. per sq. in. the value of C varies from 125 down to 75 as will be noted in Table I. Forged steel shaftings have a tensile strength of 60,000 to 70,000 lb. per sq. in. with an elastic limit of 30,000 to 36,000 lb. and steel with 3½ per cent nickel has a tensile strength of 110,000 to 125,000 lb. with an elastic limit of 80,000 to 90,000 lb. per sq. in. so that with these materials the value of C are proportionately reduced.

TABLE I. ALLOWABLE STRAIN AND VALUE OF C FOR COLD ROLLED STEEL SHAFTING

Shaft Service	Load Characteristic	Strain, lb. P. sq. in.	Value of C
Head Shaft	Shock	2800	125
Head Shaft	Steady	3000	110
Jack Shaft	Shock	3000	110
Jack Shaft	Steady	3200	100
Line Shaft	Shock	3200	100
Line Shaft	Medium	3500	90
Line Shaft	Steady	4000	75
Counter Shaft	Average	4000	75

SPACING OF BEARINGS

No specific directions can be laid down to cover the spacing of bearings on power transmission shafting; each case is usually a separate problem but to prevent heating and binding of bearings the deflection between bearings must not exceed 0.01 in. per foot of shaft length. For cold rolled steel shafting merely transmitting power, the maximum allowable distance between bearings may be calculated by the formula

$$C = \sqrt[3]{873\,d^2}$$

In which C is the maximum distance between bearings in feet and d is the diameter of the shaft in inches.

For shafts carrying average pulley load and allowing an average of 40 lb. per in. of width for the pull of the belting, the formula used is

$$C = \sqrt[3]{175\,d^2}$$

In general practice, the custom is, for head shafts, to supply a bearing on each side of each pulley; for jack shafts, two bearings; for line shafts, space bearings every 6 ft. to 8 ft.; for counter shafts, two or three bearings.

PROPER SPEED FOR LINE SHAFT

Factors determining the proper speed for the line shaft are the character of the work to be performed by the installation and the speed of the main drive belt. Within reasonable limits, the high-speed shafting is less expensive to install than that running at low speed, owing to the decreased size and weight of shafting, belts, pulleys, bearings and other accessories but the maintenance is increased due to wear on bearings, alinement difficulties caused by vibration and general wear and tear on the whole system.

Line shafting in machine shops is usually designed for a speed of 120 to 180 r.p.m. while, in woodworking shops, speeds commonly employed range from 250 to 300 r.p.m. and in textile mills the line shaft speeds run from 300 to 400 r.p.m.

SUPPORTING THE SHAFT

To give satisfactory service, the shafting must be rigidly supported; a support subject to even slight movement or vibration is sure to give troubles that are characteristic of poor alinement. In usual practice, shafting is supported through bearings and their framework attached to overhead beams, building posts or built-up piers. The general shape of the bearing framework is triangular with the bearing in one corner which insures

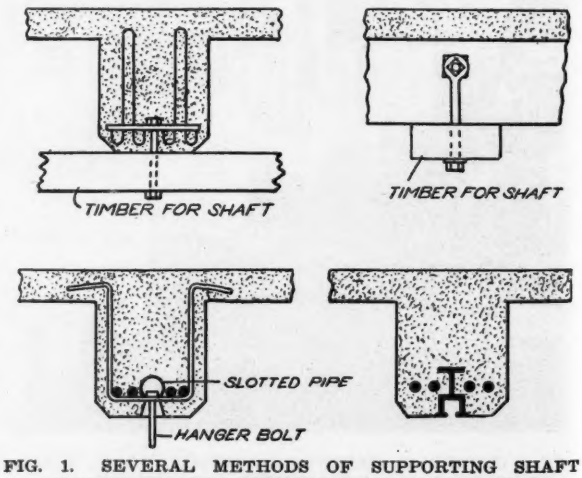


FIG. 1. SEVERAL METHODS OF SUPPORTING SHAFT HANGERS FROM OVERHEAD CONCRETE BEAMS

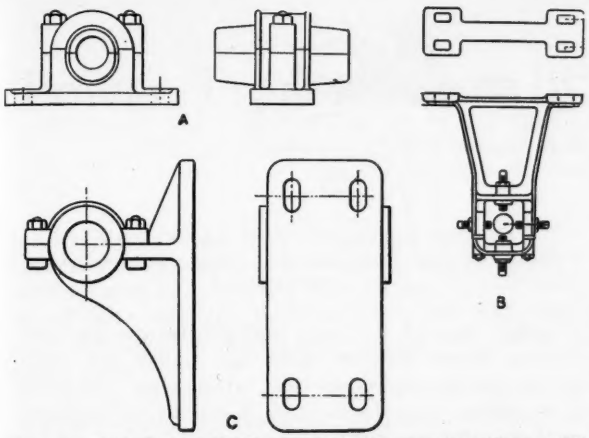


FIG. 2. GENERAL FORMS OF PILLOW BLOCK, DROP AND WALL HANGERS

rigidity when attached to unyielding supports. Several methods of attaching hangers to overhead beams are illustrated in Fig. 1 while the general form of bearing supports are shown in Fig. 2.

Good practice would indicate that the pressure per square inch of bearing surface should be from 400 to 800 lb. for shafting. In general transmission, this has solved itself into certain ratios of length of bearing to the diameter of the shaft. For shafts under 100 r.p.m., 2¾ times the shaft diameter should be the length of the bearing; while from 100 to 350 r.p.m. at least three diameters should be used. A bearing that is subjected to too great a pressure will run hot regardless of the amount of lubricant used.

Shaft bearings are almost universally lined with some composition of babbit metal which is comparatively soft and ductile and, with careful attention to alinement and lubrication, the surface takes on a high polish in service.

Three methods of lubricating shaft bearings are in common use, namely, grease cups, wick oiling and ring oiling, with the latter growing in favor.

Ball and roller bearings have, during the past few years, broadened their field greatly but are not as yet used extensively on mill and shop power shafting.

Shaft Alinement

To keep the loss of power down to the minimum, requires the closest attention and accuracy in the alinement of the shafting. Although the method adopted for establishing a line for the shafting or correcting the alinement must be worked out to suit each individual installation, one commonly employed is first to establish an accurate line by the use of a stretched wire to which the line of shafting can be compared. This reference line is usually placed directly over the shaft, its level being accurately determined by means of a spirit level and its position in regard to the machinery and building accurately measured.

With the reference line accurately placed and the shafting supported in its bearings, measurements are taken both horizontally and vertically from this line of reference to the shafting and by means of the adjustment provided in the shafting supports, accurate alinement can be secured. Checking the alinement in the vertical plane can be done by means of a carpenter's level, leveling rods, leveling hose or surveyor's transit or level. Alinement in the horizontal plane may be accurately checked by means of plumb bobs dropped from various points along the line of shafting.

When testing the alinement of a line shaft, a record similar to that shown in Fig. 3 is convenient as it indicates the amount of adjustment which is required and points out the bearings that may not be properly supported.

DATE ----------

BEARING NO.	IN. HIGH	IN. LOW	IN. TO EAST	IN. TO WEST
1				
2				
3				
4				
5				
6				
7				
8				

INSTRUMENT USED----------

OPERATOR

FIG. 3. CONVENIENT FORM FOR USE IN ALINING SHAFTING

Couplings

To extend a shaft that is too short or to provide a means for dividing a shaft to make it more convenient to handle, the usual appliance employed is some form of coupling, several types being illustrated in Fig. 4.

Of recent years a number of flexible couplings have come into extensive use, particularly to connect the shafts of two machines such as turbine and generator, motor and generator, engine and draft fan. These couplings permit of slight misalinement of the two shafts without binding the bearings and are available in designs suitable for high and low speeds.

Clutches

In nearly every shop, an advantage is gained in grouping the machinery so that each group or large individual machine may be run as a unit without interfering with the operation of other driven machinery. This necessitates means for cutting in or out sections of shafting or individual pulleys while the driven section of the shaft is in operation. In many cases this service is most conveniently accomplished by means of friction clutches which take hold or release gradually thus preventing sudden shock to either the driving or driven elements.

In cases where it is desirable to connect or disconnect shafting running at low speed and where shock is of

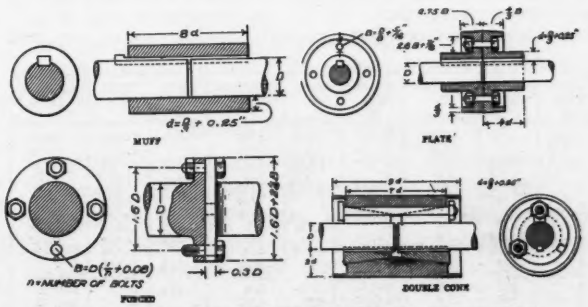


FIG. 4. SEVERAL TYPES OF SHAFT COUPLINGS

little consequence, either the square-jaw or spiral-jaw clutch operates in only one direction.

When selecting a clutch, four factors should be thoroughly considered, i.e., the load condition, speed of clutches, power used and method of application, and the operating conditions of the clutch.

Pulleys for Shafting

Belt contact surface of the pulley should be smooth and present a high coefficient of friction. Slippage cannot be entirely eliminated so a rough surface will wear the belt unduly.

Pulley weights should be as light as possible consistent with the strength necessary to withstand the load placed upon the pulley and the severe shocks likely to occur in service. Too much weight loads the shaft unnecessarily, increases bearing friction, puts undue strains on supports and increases initial costs.

As belt slip is always present when the pulley is in service, heat will be generated at the surface and this must be conducted away, so a good heat conducting surface is desirable.

Pulleys that can be installed easily have advantages in services where lost time is of importance. Split pulleys are recommended for such service.

Pulleys that can be adjusted to shafts of different diameters should be considered where there is a likelihood that they may be used in different places.

Materials used and construction employed should be such as not to be effected by the atmospheric conditions surrounding the installation, such as humidity, heat, steam or chemical fumes.

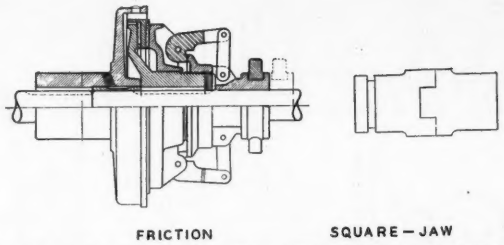
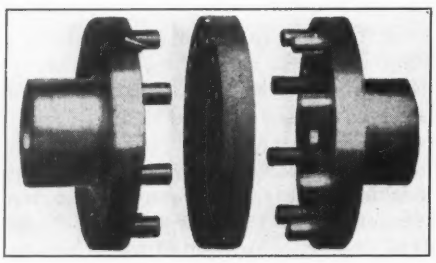
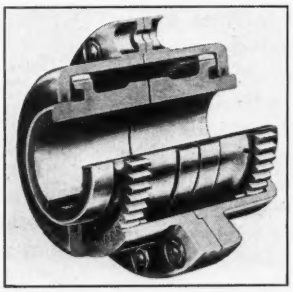


FIG. 6. TYPES OF FRICTION AND SQUARE JAW TYPE CLUTCHES





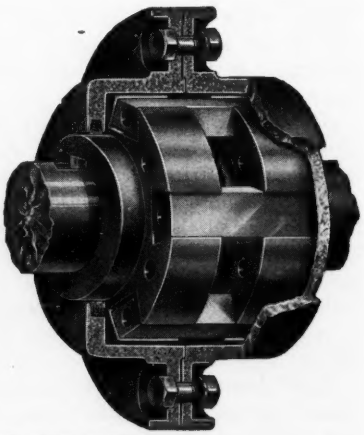


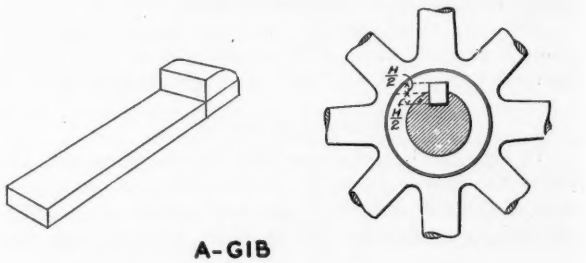
FIG. 5. FLEXIBLE SHAFT COUPLINGS—FIBER DISK, GEAR AND KEY TYPES

Shaft Keys

To prevent the rotation of a pulley on a shaft, the common provision is a shaft key or set screws. The several types of keys in use are shown in the illustration, Fig. 7, and the dimensions of the keys commonly employed are given in Table II, these keys being fitted on all sides. The gib key is in most general use for transmitting power between shaft and pulley but under special conditions feather keys, which allow the pulley to be shifted along the shaft while still delivering power, or Woodruff keys which do not extend beyond the hub of the pulley.

TABLE II. KEY DIMENSIONS FOR VARIOUS SIZED SHAFTS

SHAFT DIAM IN	WIDTH IN	THICKNESS IN	SHAFT DIAM IN	WIDTH IN	THICKNESS IN	SHAFT DIAM IN	WIDTH IN	THICKNESS IN
1/2	7/32	3/16	3-1/4	3/4	7/16	6-3/4	1-3/8	3/4
5/8	1/4	3/16	3-1/2	13/16	7/16	7	1-7/16	13/16
3/4	9/32	3/16	3-3/4	13/16	1/2	7-1/4	1-1/2	13/16
7/8	9/32	7/32	4	7/8	1/2	7-1/2	1-9/16	7/8
1	5/16	7/32	4-1/4	15/16	9/16	7-3/4	1-9/16	7/8
1-1/8	11/32	1/4	4-1/2	1	9/16	8	1-5/8	7/8
1-1/4	3/8	1/4	4-3/4	1	9/16	8-1/4	1-5/8	15/16
1-3/8	3/8	1/4	5	1-1/16	5/8	8-1/2	1-3/4	15/16
1-1/2	13/32	1/4	5-1/4	1-1/8	5/8	8-3/4	1-3/4	15/16
1-3/4	7/16	5/16	5-1/2	1-3/16	5/8	9	1-3/4	1
2	1/2	5/16	5-3/4	1-3/16	11/16	9-1/4	1-7/8	1
2-1/4	9/16	5/16	6	1-1/4	11/16	9-1/2	1-7/8	1-1/16
2-1/2	5/8	3/8	6-1/4	1-5/16	3/4	9-3/4	2	1-1/16
2-3/4	5/8	3/8	6-1/2	1-3/8	3/4	10	2	1-1/16
3	11/16	7/16						



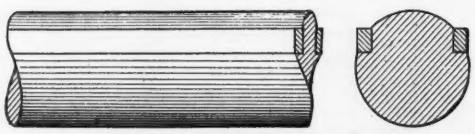


FIG. 7. COMMON TYPES OF SHAFT KEYS

Power Transmission by Various Types of Belts

CHARACTERISTICS OF MATERIALS AND ARRANGEMENTS OF VARIOUS TYPES OF BELTING. LACING AND OTHER JOINTS. SHORT-CENTER DRIVES. BELT MAINTENANCE

LEATHER STILL holds the premier place as a belt material but band belts are made also of cotton in various forms, of rubberized material and even of steel. Round belts including these materials and rope, especially that made of hemp, are used on long drives in special cases.

General properties of belts include adequate strength, flexibility, elasticity, minimum tendency to stretch, ability to grip the pulley with little slip but with no tendency to stick to the pulley, in operation, as it leaves it.

Single belting can be obtained regularly up to about $\frac{3}{16}$ in. in thickness and double (two-ply) belting up to about $\frac{3}{8}$ in. Extremely wide belting may be made of two or more strips placed laterally. The quality of leather belting may be determined by the "piping" test which consists of taking a piece of belting and doubling it up, grain side in. If the wrinkles or piping appearing on the grain side are large and coarse the leather is of poor quality. Fine, delicate wrinkles indicate firm, sound stock.

STRENGTH REQUIREMENTS

Tentative specifications for leather belting, issued by the American Petroleum Institute, require an elongation of not less than 11 per cent nor more than 24 per cent for a load of 700 for single and 1300 lb. per in. of width for double belts. A sample of belting must show no cracking when bent around a 1-in. circular mandrel, grain side out. Under the piping test a piece of belting bent 180 deg. around a 3-in. mandrel must show no signs of coarse wrinkling on the grain surface.

United States Navy specifications require oak-tanned leather for belts to show an average tensile strength of 4000 lb. per sq. in. for single and 3600 lb. for double belts. When subjected to a stress of 2250 lb. per sq. in. for one hour, single belts should show not more than 13.5 per cent elongation and double belts not more than 12.5 per cent. The modulus of elasticity in tension varies from 17,800 lb. per sq. in. for new belts to 32,000 lb. for old. The proportional elastic limit is about 2300 lb. per sq. in. The strength of chrome leather varies from 8500 to 12,900 lb. per sq. in.

RUBBER BELTS

Rubber belts are made by saturating a strong woven duck belt with rubber and subsequently vulcanizing it. Uniformity in width and thickness, durability when exposed to steam and dampness, great tensile strength and superior grip on pulleys are claimed advantages over leather belts. With proper weight of duck, a three or four-ply rubber belt is claimed to equal a single and a five or six-ply, a double leather belt. Balata belting which is canvas belting, impregnated with balata gum, is extensively employed for this purpose as it is affected very little by dampness or change of temperature. It does not age and is not affected by animal oil. Mineral oil acts upon it, however, and it is affected by temperatures of 100 to 120 deg. F. It does not stretch readily. Commercial sizes range from 1 to 60 in.

Rubber belts are especially adapted for use in damp places and out of doors or where exposed to acid fumes but they should not be used where the belt is subjected to steam or high heat. The ultimate strength of rubber belting varies from 900 to 1500 lb. per sq. in. according to the fabric used. Rubber belts appear to have a somewhat higher frictional resistance than leather belts but this may be offset by the heavier weight. Rubber belts

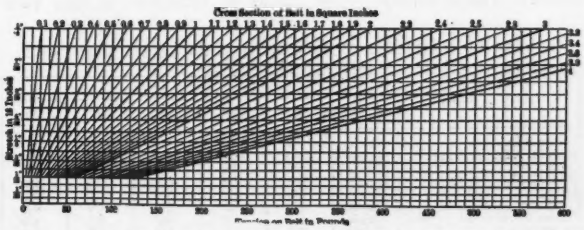


FIG. 1. RELATION OF TENSION AND STRETCH IN LEATHER BELTS

are obtainable in sizes from two-ply and one inch wide to 12-ply and 60-in. wide. Bach recommends a working tension of 100 to 150 lb. per sq. in.

COTTON BELTS

Cotton belts, when woven, have a tensile strength of about 5000 lb. per sq. in.; when sewed, from 6500 to 7500 lb. per sq. in. Canvas belting has about the same strength as leather belting. It is obtainable in different thicknesses from four-ply and 1½ in. wide to 10-ply and 60 in. wide.

STEEL BELTS

Steel belts are made from hardened steel of 190,000 lb. per sq. in. tensile strength. The initial tension should be about 10,000 lb. per sq. in. Pulleys used for steel belts are made cylindrical without crown and faced with cork covered canvas which is cemented in place. Under these conditions there is practically no slip, the coefficient of friction being 0.27. Speeds up to 19,000 ft. have been reported. Wear is inappreciable and the cost is substantially less than that of leather belts but it is necessary to use homogeneous material and to have accurate shaft alinement and center to center distance in order to assure success with this type of belt.

HORSEPOWER RATINGS OF BELTS

Belts should not be called upon to transmit, continuously, the maximum power of which they are capable or the life of the belt will be materially decreased. The horsepower a good leather belt may be expected to transmit is:

$$Hp = V W \div F$$

where V = belt velocity in ft. per min.
W = width of belt, in.
F = an experimental factor which depends on the arc of contact as given in Table I.

This formula does not take into account the reduction in power at high speed due to centrifugal action or the effect of weight of leather on the power transmitted. Tables II and III consider these factors. The columns "above" and "below" in Table III refer to the tight side of the belt. The values given apply to drives that are approximately horizontal and for pulleys larger than 36 in., the values for a 36-in. belt are supposed to be taken and for center distances above 25 ft. the values for 25 ft. are to be taken. These tables do not consider effect of arc of contact but this factor is of less importance than the size of the small pulley.

Single belts may be designed for a maximum stress of 60 lb. per inch of width with good results while two-ply and three-ply belts may have stresses up to 105 and 150 lb. respectively. The ratio of tensions in the two sides of the belt should not exceed 2 for small pulleys, 2½ for medium and 3 for large pulleys. The method of tanning has a large influence on its strength, chrome and other tanning methods may increase the power transmitted 20 per cent over oak tanned belt of same dimensions.

Power design of rubber or canvas belts may be based upon the formula:

$$Hp = W\,V \div (136 + 2640 \div N)$$

where Hp = horsepower transmitted.
W = width of belt, in.
V = velocity of belt, ft. per min.
N = number of plies.

For balata belts:

$$Hp = 0.000158\,W\,D\,(N - 1) \times \text{r.p.m.}$$

where D = pulley diameter, in.

Effective pulls for various widths and thicknesses of rubber belt are given in Table IV.

TABLE I. FACTORS FOR VARIOUS ARCS OF CONTACT

Diam. of pulley	Belt	Arc of contact				
		120°	140°	160°	180°	200°
Under 8 in.	Single	1400	1270	1180	1100	1040
8–36 in.	Single	1240	1100	990	920	860
Over 3 ft.	Single	1100	980	890	830	770
Under 14 in.	Double	800	730	670	630	590
14–60 in.	Double	700	630	570	520	480
Over 5 ft.	Double	630	560	510	470	440
Under 21 in.	Triple	560	520	480	440	410
21–84 in.	Triple	490	450	410	370	340

TABLE II. HORSEPOWER OF LEATHER BELT PER INCH OF WIDTH

Weight of belt	Belt speed, ft. per min.											
	500	1000	1500	2000	2500	3000	3500	4000	5000	6000	7000	8000
Light single	.75	1.45	2.16	2.87	3.53	4.15	4.70	5.20	5.95	6.30	6.15	5.45
Medium single	.90	1.80	2.68	3.55	4.35	5.15	5.80	6.42	7.35	7.78	7.57	6.76
Heavy single	1.05	2.06	3.10	4.10	5.05	5.93	6.70	7.40	8.42	8.92	8.75	7.76
Light double	1.25	2.53	3.76	4.95	6.10	7.17	8.12	9.00	10.30	10.92	10.65	9.48
Medium double	1.52	3.08	4.60	6.00	7.40	8.70	9.90	10.95	12.50	13.22	12.90	11.55
Heavy double	1.77	3.55	5.30	6.95	8.55	10.05	11.45	12.60	14.35	15.22	14.85	13.20
Medium triple	2.05	4.10	6.10	8.05	9.88	11.60	13.15	14.50	16.52	17.55	17.10	15.30

TABLE III. CORRECTION FACTORS FOR BELT POWER DETERMINATION

Diameter of smaller pulley, in.	Center distance, ft.															
	4		6		8		10		12		15		20		25	
	Above or below	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below
4	.53	.54	.55	.55	.57	.56	.59	.57	.61	.58	.63	.59	.65	.59	.66		
5	.59	.60	.62	.62	.64	.63	.66	.63	.68	.65	.70	.66	.72	.66	.74		
6	.62	.63	.65	.65	.68	.66	.70	.67	.72	.68	.74	.69	.76	.70	.78		
8	.66	.67	.69	.69	.72	.70	.74	.71	.76	.72	.78	.73	.80	.74	.82		
10	.68	.70	.71	.71	.74	.73	.77	.73	.79	.75	.81	.76	.83	.77	.85		
12	.70	.72	.74	.73	.77	.75	.79	.76	.81	.77	.83	.78	.86	.79	.88		
15	.73	.74	.76	.76	.79	.77	.82	.78	.84	.80	.86	.81	.89	.82	.91		
18	.75	.76	.78	.78	.81	.79	.84	.80	.86	.82	.89	.83	.91	.84	.93		
24	.77	.79	.81	.81	.84	.82	.87	.83	.89	.85	.92	.86	.94	.87	.96		
30	.79	.81	.82	.82	.86	.84	.89	.85	.91	.87	.94	.88	.96	.89	.98		
36	.80	.82	.84	.83	.87	.85	.90	.86	.92	.88	.95	.89	.98	.90	1.00		

TABLE IV. EFFECTIVE PULL PER PLY AND INCH OF WIDTH FOR RUBBER BELTS

Belt velocity, ft. per min.	28 ounce duck							36 ounce duck						
	Arc of belt contact, deg.													
	160	180	200	220	240	260	280	160	180	200	220	240	260	280
100	3.86	4.25	4.65	5.01	5.36	5.70	6.02	6.16	6.74	7.30	7.78	8.30	8.70	9.13
500	5.34	5.83	6.33	6.72	7.20	7.57	7.90	7.63	8.28	8.86	9.42	9.91	10.38	10.79
1000	6.65	7.21	7.73	8.20	8.60	9.00	9.37	8.79	9.44	10.03	10.56	11.04	11.50	11.88
1500	7.70	8.20	8.79	9.24	9.65	10.03	10.32	9.98	10.63	11.19	11.69	12.10	12.40	12.80
2000	8.24	8.87	9.40	9.78	10.12	10.45	10.71	10.70	11.31	11.78	12.19	12.50	12.80	13.06
2500	8.86	9.33	9.78	10.12	10.41	10.65	10.88	11.23	11.70	12.06	12.34	12.55	12.78	12.90
3000	9.25	9.64	9.97	10.22	10.45	10.60	10.74	11.70	11.94	12.11	12.24	12.33	12.41	12.48
3500	9.46	9.67	9.89	10.03	10.12	10.21	10.28	10.33	10.61	10.81	10.98	11.10	11.18	11.25
4000	8.90	9.07	9.20	9.30	9.35	9.39	9.44	8.15	8.52	8.82	9.05	9.24	9.40	9.54
4500	7.02	7.28	7.50	7.69	7.82	7.93	8.08	6.10	6.47	6.78	7.03	7.23	7.44	7.68
5000	5.12	5.47	5.72	5.91	6.08	6.22	6.31	4.03	4.33	4.62	4.85	5.05	5.25	5.41

Belt Speeds

Belt speeds for different diameters and speeds of pulleys may be taken directly from the alinement chart, Fig. 2. Due to centrifugal action, high speed tends to throw the belt away from the pulley hence to reduce the arc of contact, from what would be 180 deg. at normal speed to as little as 110 deg., proportionately reducing its power transmission ability.

While belts have been operated at 8000 f.p.m. and speeds of 7000 are common for such machines as edger belts in lumber mills, high speed drives are troublesome. When belts, alinement and pulleys are in best condition 6000 f.p.m. may be allowed but usually the maximum speed should be set at 5000 f.p.m. Much trouble has been overcome in mills by reducing sizes of pulleys, thus reducing the belt velocity without altering the shaft r.p.m.

Belt Tension

Effective tensions at various velocities, in feet per minute per inch of width for single leather belts with 180 deg. arc of contact and allowing an ample factor of safety and considering the effect of centrifugal force are:

Belt speed	1000	2000	3000	4000	5000	6000
Effective tension	72	68	65	60	53	45

Continuous maintenance of excessive tension greatly increases the stretch in a leather belt hence excessive tension should be avoided by the selection of a wider belt. The influence of tension on stretch of a belt is shown in Fig. 1. For double belts these figures should be multiplied by 1.6 and for 3-ply belts, by 2.

Arc of contact on the smaller pulley for various pulley diameter differences and center to center distances may be obtained directly from the chart Fig. 3. Approximately, the arc of contact in degrees on the smaller of two pulleys connected with an open belt is equal to $181 - [60\,(D - d) \div L]$ where D and d are the pulley diameters and L, the distance between their shaft centers all dimensions being in inches. This formula gives values not over 0.5 per cent in error.

Oldest among belt joints is the laced type. Formerly leather thongs were used; today rawhide and wire lacing are employed. If rawhide lacing is properly applied, a good joint results and where hand shifting is

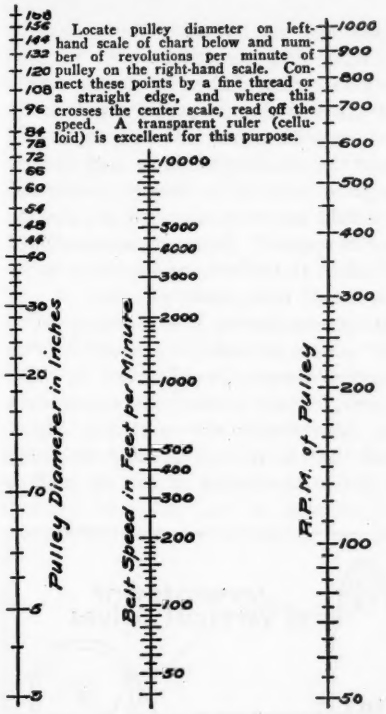

Locate pulley diameter on left-hand scale of chart below and number of revolutions per minute of pulley on the right-hand scale. Connect these points by a fine thread or a straight edge, and where this crosses the center scale, read off the speed. A transparent ruler (celluloid) is excellent for this purpose.
Pulley Diameter in Inches
Belt Speed in Feet per Minute
R.P.M. of Pulley

FIG. 2. BELT SPEED CHART

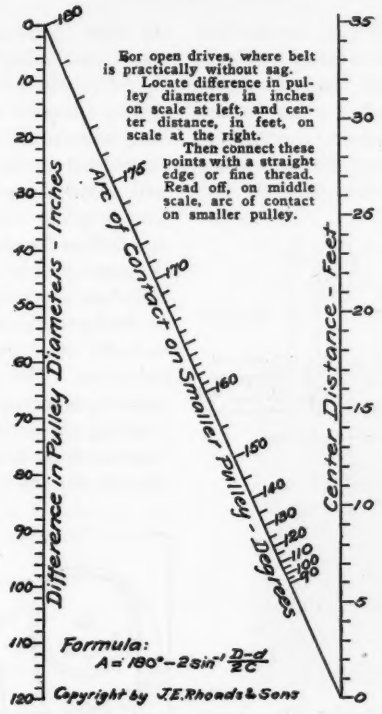

For open drives, where belt is practically without sag.
Locate difference in pulley diameters in inches on scale at left, and center distance, in feet, on scale at the right.
Then connect these points with a straight edge or fine thread. Read off, on middle scale, arc of contact on smaller pulley.
Difference in Pulley Diameters - Inches
Arc of Contact on Smaller Pulley - Degrees
Center Distance - Feet
Formula: A = 180° − 2 sin⁻¹ (D−d)/2C
Copyright by J.E. Rhoads & Sons

FIG. 3. DETERMINATION OF ARC OF CONTACT

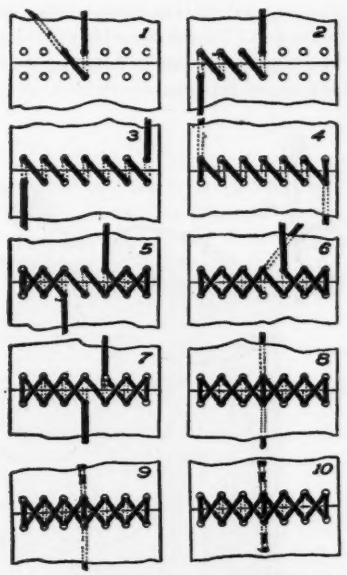


FIG. 4. DIAGRAM SHOWING BACK OF BELT AND INDICATING PROPER METHOD OF LACING A BELT WITH RAW HIDE

necessary this method should be employed where joints are necessary because of its safety feature to the machine operator. A poor and improperly laced joint is detrimental to both belt and production. The modern wire lace produces a smoother joint than rawhide but does not last as long.

All belt joints must be square at the ends. Accepted practice in punching the holes for rawhide lace is five holes in belting 4 in. wide and a proportionate number of holes, according to the width of the belt. One hole always should be in the center so that at the start of the lacing operation the two ends of the belt may be brought together in line. Proper method of lacing a belt is shown in Fig. 4.

Belt Hooks

Use of hooks, made of a special steel wire possessing high tensile strength, the ends of which are sharpened to a point, is illustrated in Fig. 5. These hooks are applied by means of a hand-operated machine. Another wire hinge joint is made by sewing rings of wire around the ends of the two belt ends. A pressed metal hinged hook made of monel metal is illustrated in Fig. 6. The prongs of this hook are turned so as to penetrate the belt in the line of running in order to avoid cutting the belt fibers, thus weakening it. This hook is applied by means of an ordinary hammer. Rawhide or fiber hinge pins are generally used in these hinges; one manufacturer uses a monel-metal, rocker-hinge pin which is made of two parts having rolling surfaces affording ample movement. Plate fastenings which are riveted to the belt by split steel rivets which, upon being inserted in the plate and hammered through the belt, spread on the pulley side, afford a smooth running surface.

Wherever possible, endless belting should be used. Wide belts and all belts that run at high speed over

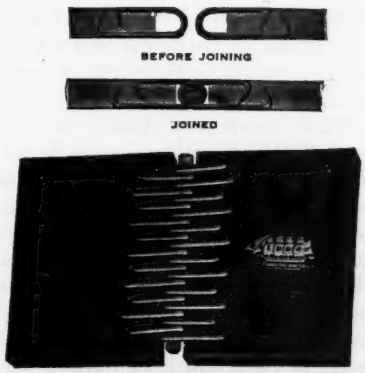


FIG. 5. APPLICATION OF WIRE HOOKS SHOWING (ABOVE) METHOD OF JOINING THE BELTS AND (BELOW) THE FINISHED LACED JOINT

FIG. 6. PRESSED-STEEL, HINGED BELT HOOK

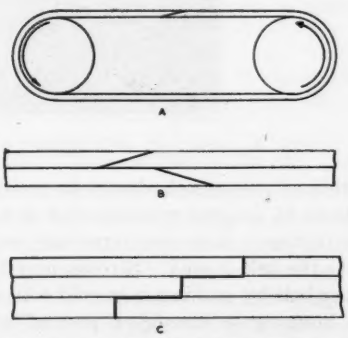


FIG. 7. ENDLESS-BELT JOINTS: A, FOR SINGLE LEATHER BELT; B, FOR DOUBLE LEATHER BELTS, AND C, FOR CANVAS, RUBBER AND SOME WOVEN BELTS

small pulleys give better satisfaction, run truer, last longer and require fewer stops when made endless. Belts are made endless best by the manufacturer. Rubber and balata belts should be made endless at the factory. The cemented splice is the best but entails a lengthy operation. Allowance for lap for a leather belt depends upon the width of the belt as follows:

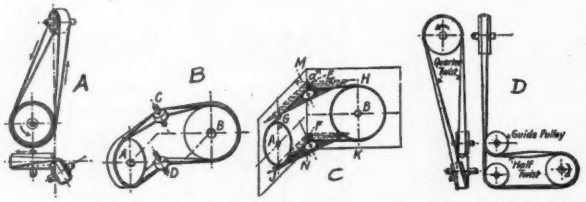


FIG. 8. ARRANGEMENTS FOR BELT DRIVES

Single Belt

½ in.	to 3 in.	wide	allow 4 in. for lap
3¼ in.	to 4¼ in.	wide	allow 5 in. for lap
5 in.	to 7 in.	wide	allow 6 in. for lap
8 in.		wide	allow 7 in. for lap

Double Belt

1 in.	to 3 in.	wide	allow 6 in. for lap
3¼ in.	to 6 in.	wide	allow 7 in. for lap
6¼ in.	to 9 in.	wide	allow 8 in. for lap
9¼ in.	to 12 in.	wide	allow 10 in. for lap
12¼ in.	to 14 in.	wide	allow 12 in. for lap
14¼ in.	to 18 in.	wide	allow 14 in. for lap
Wider than 18 in.		wide	allow 16 in. for lap

Belt Stretch

Some manufacturers indicate, on their belts, the direction they are to run; these directions should be followed. Before starting to splice a belt, as much as

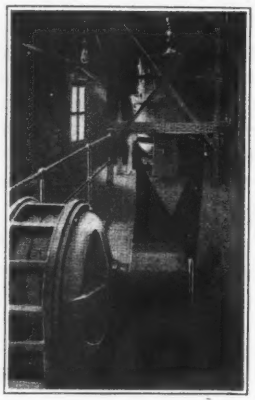


FIG. 9. SPECIAL QUARTER-TWIST DRIVE

possible of the stretch should be removed. This stretch is about ¼ in. per running foot for new belts. Some manufacturers now are removing most of this stretch before the belt is sold. Stretch may be removed from a leather belt by soaking it in cold water for several hours then running it through a pair of rollers such as tinsmiths use, then, after tightening the rollers a little more, run it through again on its opposite side. In preparing the lap of a single belt the ends must first be squared then shaved down on opposite surfaces of the belt. This is done best by fastening the ends to a board and using a carpenter's plane.

After the belt has been placed over the pulleys, each end is clamped and the two clamps pulled together by long bolts until the belt ends are lapped properly. The shaved portions should then be roughened up and treated with cement; waterproof cement is usually preferred. Two priming coats should be given, allowing the first to dry before the second is applied. Squeeze clamps should be prepared for use before the third application is made. This last application should be a generous one.

Before adjusting squeeze clamps it is a good plan to tack the lap together and to a board to prevent it from swinging. The squeeze clamps should stand 30 min. before removing them. Most authorities recommend running the splice in the direction shown at A in Fig. 7 because it is claimed that there is a greater tendency for the lap to lift due to the action of the air and to

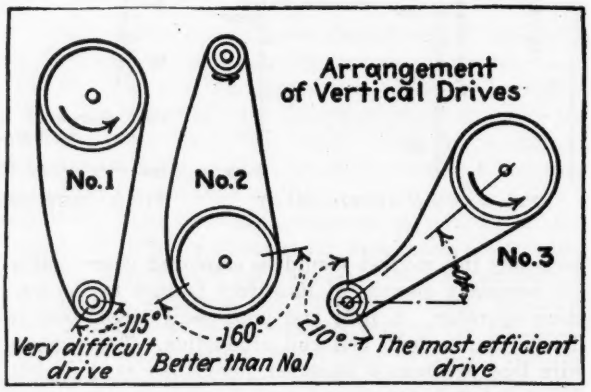


FIG. 10. VERTICAL DRIVE ARRANGEMENTS

external obstruction than to the smooth surface of the pulley.

Belting Arrangements

For installing belt drives, a simple rule which applies to all conditions, is that the center line of the belt advancing on the pulley should lie in a plane passing through the mid section of the pulley at right angles to the shaft. Shafts inclined to one another require connection as shown at A in Fig. 8. Where guide pulleys are required, their positions can be determined as shown at B, C and D. At C the center circles of the two pulleys to be connected are set in correct relative position in two planes, A being the angle between the planes. If any two points as E and F be assumed on the line of intersection MN of the planes and tangents EG, EH, FJ and FK be drawn from them to the circles, the center points of the guide pulleys must be so arranged that these tangents are also tangents to them as shown.

Slight misalinement is counteracted by crowning the pulleys, therefore is not readily noticed in drives on moderate centers but with short centers even slight misalinement will cause trouble. High crowning, however, is liable to crack the belt in time. Pulleys on which belts are shifted, such as tight and loose pulleys, should not be crowned.

Crossing belts should be avoided wherever possible especially with belts over 8 in. wide because of the

rubbing effect between them. Sometimes this may be done by introducing an idler pulley. A crossed belt should not be expected to transmit more than 75 per cent of its rated capacity as a straight drive and, in case of pulley ratios of 3 to 1 it should not be more than 50 per cent. Where crossing is used the two pulleys should be the same size, if possible, so as to make the belt cross midway between the pulleys.

Where large pulley ratios must be used and a reversed drive cannot be used, the location of an idler will help to make the belt cross at a point where rubbing will be reduced to a minimum. A crossed belt will run better from a small driving pulley than it will from a large driving pulley to a small driven pulley. Quarter-twist drives such as shown at D, Fig. 8, should also be avoided as they are troublesome and waste power. Where they are necessary, leather belting should be used as there is always a twist in a drive of this kind and this can be taken care of most easily in the lap of a leather belt when constructed for this class of drive.

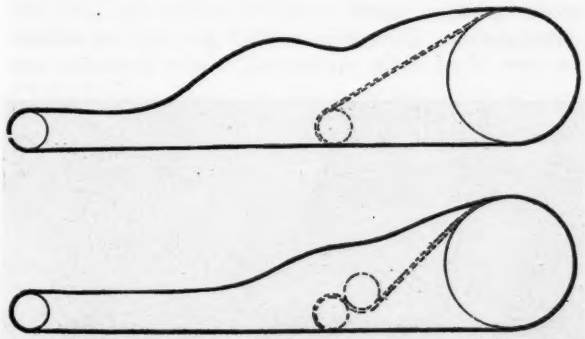


FIG. 11. IRREGULAR LOADS CAUSE A STRONG, WAVELIKE MOTION IN DRIVES WITH LONG CENTERS

A wide quarter-twist belt absorbs considerable power due to the wiping-off effect caused by the belt as it is pulled off of the driven pulley. This may be corrected by the installation of an idler pulley.

If both driving and driven pulleys are large, two idlers should be placed on the slack side; one near each pulley. This has the effect also of increasing the wrap on each pulley hence of increasing the power that may be transmitted. A horizontal quarter-twist belt should be 10 per cent wider than a normal belt under the same conditions. In the quarter-twist drive shown in Fig. 9 the belt, before being made endless, was given a loop over the smaller pulley so as to cause the grain side to run continuously on one pulley while the flesh side runs next to the other pulley.

Idler Drives

At its best, maintenance of idler drives is difficult owing to the excessive transverse strains applied to belting. Flanged mule pulleys are sometimes employed to assist in keeping the belt on the pulleys but, unless the proper type of belting is employed, rapid curling of the belt edge is the result. Best results with this class of drive are obtained when the belting is not over 1½ in. wide. It should never be employed when the belting is over 6 in. in width.

Idler pulleys should be placed to operate against the slack side of the belt and as near to the smaller pulley as possible. Where an idler is not used and where it is possible to do so, it is best to have the tight side of the belt below and the slack side over, as this effects a greater amount of wrap on the pulleys. Due to sag of belt around the lower pulley, vertical drives lose much power and require special consideration. As shown in Fig. 10, a 40-deg. drive is much more desirable than a vertical drive.

Short Center Drives

Drives with moderate or long centers are always objectionable where the pulley diameters are extremely

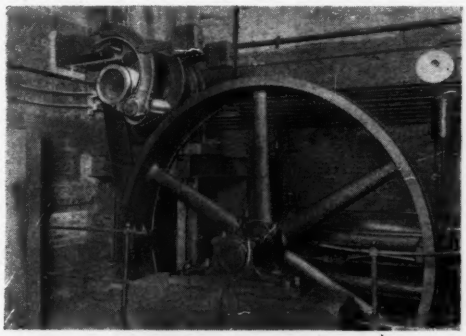


FIG. 12. SHORT-CENTER DRIVE WITH WRAPPER DEVICE

small, particularly where they operate in a horizontal position with the slack side of the belt on top because of the likelihood of the belt rubbing together. For high-speed belts, where the load is variable, shorter centers are more suitable than long centers because of the flapping of the slack length of belt as illustrated in Fig. 11 and this may result in unevenness of load. Shortening the belt, in the above case, decreases the arc of contact but this may be corrected by proper application of an idler as shown, thus increasing the wrap over that of the long drive. Employment of short drives reduces the amount of servicing necessary in shortening the belt due to stretch because of the greatly decreased

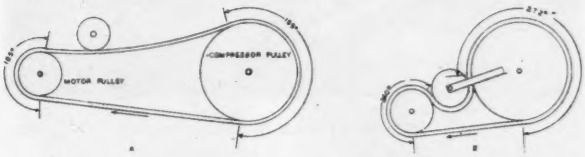


FIG. 13. DIAGRAM SHOWING ADVANTAGE OF WRAPPER DEVICE IN INCREASING BELT CONTACT

number of cuttings that need be made in comparison with long drives. Especially is this true with vertical drives.

Belt Wrappers Improve Short Drives

Application of a belt wrapper to a short-center drive in which the center to center distance is so short that only a small clearance is left between the two pulleys and the belt-wrapper pulley, is illustrated in Fig. 12. The gain in increased belt contact accomplished by use of a properly located belt wrapper device is shown in Fig. 13. In air compressor units it is customary to attach the idler to the compressor frame as indicated at B. If the distance between the pulleys is short as shown, this arrangement serves well but usually it would be

better to attach the arm to the motor frame but this would require a slight change in the motor frame preventing use of standard construction. Wrapper devices are particularly useful in vertical drives.

Belt speeds up to 8000 f.p.m. are practicable with wrapper construction and centrifugal force is in no way detrimental because any slack in the belt is automatically wrapped around the pulleys. This device also compensates for any change in belt length due to atmospheric or load conditions and required belt tensions are considerably less than those needed with a corresponding open drive. Efficiencies of 98 per cent are attained regardless of whether the tight side of the belt is on

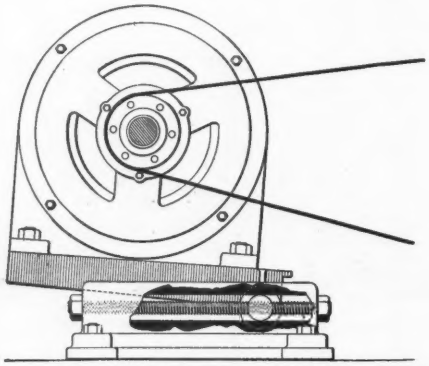


FIG. 14. HINGE ENABLES BELT TO TAKE CARE OF ALL LOADS AUTOMATICALLY, WITHOUT SLIPPING OR BURNING THE BELT

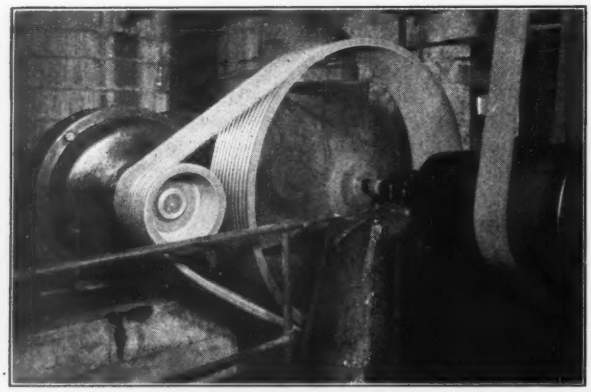


FIG. 15. MULTIPLE V-ROPE DRIVE

the top or bottom of the drive and speed ratios of 1 to 20 are practical with this construction. Belting used with wrappers should be endless and flexible.

Another type of flat belt drive which has been offered on the market recently and which is well suited for comparatively small powers, uses two standard pulleys and a standard belt of leather, rubber or fabric as shown in Fig. 14. In this, the belt tension is maintained by the weight of the motor supported on a hinged, spring balanced support which is adjustable.

Multiple V-Rope Drives

Drives of the multiple V type, arranged as shown in Fig. 15, employ a number of trapezoidal shaped belts of fabric or rubber as the transmission medium. Power is transmitted by the friction of the trapezoidal belt section against the sides of the sheave grooves. Such arrangements are compact; the distance between the rims of the pulley and sheave may be only a few inches. The drive is elastic and reversible and speed ratios as high as 7 to 1 are possible. Belt speeds as high as 6000 f.p.m. are possible but most satisfactory results are obtained at a speed of about 4000 f.p.m. The efficiency of this drive when properly maintained is 98 per cent.

Chain Belt Drives

Short center drives are frequently fitted with "silent chains" as shown in Fig. 16. These drives are especially adapted for transmission where the motion must be positive and where considerable power must be transmitted per inch width of driving element. They employ a toothed metallic transmission medium that is inelastic although a limited amount of play is available in the component parts of the chain. Special provision for elasticity can be made by the introduction of springs in the rims of the sprockets but this is used only where frequently fluctuating loads are encountered.

Chain speeds of from 1800 to 2000 f.p.m. are recommended; higher speeds result in considerable noise and deterioration. Efficiencies of 98.2 per cent are claimed for new silent chain equipment. Under favorable con-

FIG. 16. CHAIN LINK DRIVE

ditions, reduction ratios of as high as 15 to 1 have been used in one reduction, but it is desirable to use ratios not higher than 7 to 1. Where large ratios are used, the minimum center distance is usually about 0.8 times the difference between the diameters of the two sprockets. This drive is a reversible one. It should not be installed for vertical drives where the smaller sprocket is the lower one because the weight of the chain tends to drop it from its proper engagement with the smaller sprocket.

Belts should receive attention before they break down. Belts that have broken down or have been damaged at the edges may be cleaned, redressed, cemented into a continuous long strip and trimmed at comparatively low cost by manufacturers who have special facilities for this service.

When pulleys acquire a high polish it is an indica-

tion that the belt is dry and its surface glazed, hence that it slips unduly on the pulley. A dry belt will also wear internally due to friction of its fibers. After a dry belt has been conditioned properly, the polish on the face of the pulleys will gradually disappear.

Oil from bearings, in time, may so saturate a belt that it will fail to pull without excessive slippage and tension. As a temporary relief, a liberal sprinkling of chalk on the surface will absorb the oil. As soon as some of the oil has been absorbed, the chalk should be scraped off and the application repeated.

Belt Cleaning Methods

Oil may be removed from a belt by soaking it for about two days in gasoline, naphtha, kerosene or benzol, which are inflammable, or in carbon tetrachloride, which is not inflammable. Immerse the loosely wound coil, on edge, in the liquid and allow it to soak over night. Then stand it on its other edge for about 10 hr. If the belt is dirty as well as oily, most of the dirt, usually, will settle to the bottom. Dirt that does not loosen and settle may be removed by brushing or scraping.

Belt Dressings

After cleaning the belt, stretch it out on the floor to dry. Drying may be expedited by passing the belt through rolls. After drying, a good belt dressing which will make the belt pliable and penetrate the fibers and lubricate them, should be applied. Belt manufacturers are prepared to furnish or recommend a proper dressing for their belts.

Types of Gears For Industrial Use

Modern, High Speed Accurately Cut Gears Are a Comparatively Recent Development

GEARS have been used for many hundreds of years but only recently has this branch of engineering advanced to its present high state of development. In fact, we may truthfully say that the development of the turbine, primarily a high speed machine, created the demand for high speed, accurately cut and efficient gears which forced the development of accurate gear cutting machines.

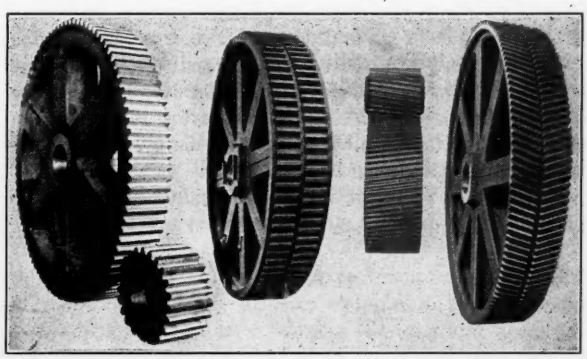


FIG. 1. A, SPUR GEAR AND PINION. B, MACHINE MOLDED STAGGERED GEAR. C, HELICAL GEAR AND PINION. D, DOUBLE HELICAL GEAR

Straight tooth spur gears such as shown in Fig. 1A are the oldest and most common type, for transmitting power between parallel shafts. They are entirely satisfactory for slow speeds but for high speeds have inherent disadvantages of noise and shock because usually the load is carried by one tooth at a time. To distribute this load more evenly staggered teeth such as illustrated in Fig. 1B were introduced. Sometimes three rows of teeth are used to distribute the load over a greater number of teeth.

If this staggering were carried out in an infinite number of steps, it would result in helical gears of the type shown by Fig. 1C. If this type of gear is accurately cut, the load is passed from tooth to tooth in a continuous manner without shock or impact. It is obvious, however, that this type of gear develops an end thrust and to obviate this double helical gears with opposing angles are used as shown in Fig. 1D.

Another example of double helical gear, in this case that of a modern, high speed, high efficiency type, is shown in Fig. 2A. Sometimes the two gears are cut separate and joined together later as in Fig. 2A sometimes the opposing teeth are cut from the same blank, as shown in Fig. 2B, and are then called herringbone gears. Until recently machines for cutting continuous herringbone teeth were not available, making it necessary to leave a small path between the two for clearance of the cutting tool. This resulted in a groove similar to that shown in Fig. 1D. On the large gears, the helical

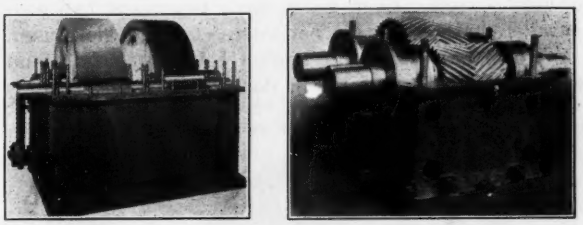


FIG. 2. MODERN HIGH SPEED GEARS, A, DOUBLE HELICAL, B, CONTINUOUS HERRINGBONE

teeth appear to be straight but they are actually curved as can be seen from the pinion in Fig. 2A.

Usual practice divides gears into two general classes: gears and pinions, the latter term being applied specifically to the driving and the former to the driven member. Originally the entire gear including the teeth was cast, using wooden patterns. This practice was later improved by introducing accurate molding machines with the tooth block made from metal or hardwood. Figure 1B is an excellent example of machine molding practice. Today, however, the majority of gears are cut or machined in order to get the accuracy necessary to

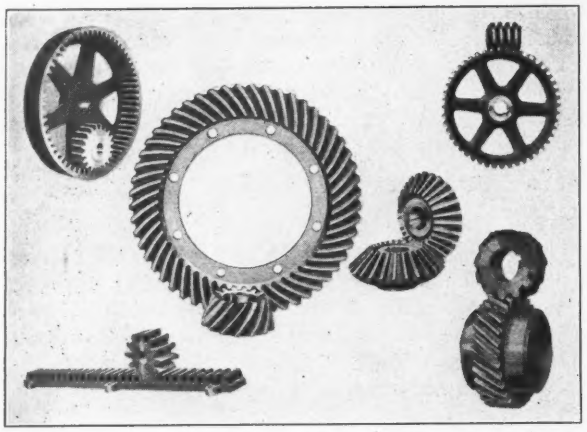


FIG. 3. A, INTERNAL SPUR GEAR. B, RACK AND PINION. C, CURVED TOOTH BEVEL GEARS. D, MITRE GEARS. E, WORM GEAR. F, SPIRAL GEAR

give long life, and smooth operation with high speeds and heavy loading.

In some cases where extreme flexibility and noiselessness are demanded, pinions molded and cut from fiber, cloth, wood, rawhide, bakelite and other materials are used to absorb the shock. Mortise gears of the type shown in Fig. 4A used to be common. The teeth are replaceable hardwood blocks held in place by wedges.

In addition to the types of gears mentioned above, a number of others are in common use. Internal gears, Fig. 3A, are often used where space is limited, while the rack and pinion, Fig. 3B, are in common use for transmitting motion in a parallel plane. Another common type is the bevel gear as shown in Fig. 3C. They are used for transmitting motion between two shafts which intersect at an angle. In general the gears are parts of cones whose vertexes coincide and for this reason must always be made and used in pairs. If the shafts intersect at 90 deg. and both gears are the same size, as in Fig. 3D (i.e., a 1 to 1 ratio), they are known as mitre gears. Either type can be made with straight or curved teeth. Skew gears, made to connect two non-parallel shafts which do not intersect, are seldom used.

Worm gears transmit motion between shafts at an angle of 90 deg. but which do not intersect. This is fundamentally a screw meshing with a gear as shown in Fig. 3E. A special form of this known as the helical, or more commonly spiral gear, is shown in Fig. 3F. This is the same as the worm in action but the helix angle is greater so that instead of the steady forward motion of screw the action is confined to one or two teeth at a time.

Intermittent gears, Fig. 4B, are used where it is necessary to stop the motion of one or more gears while the others continue in motion. Other special types which may be considered as closely related to the gear is the sprocket wheel for chains two forms of which are shown in Figs. 4C and 4D and the friction Fig. 4E. The latter is a special form without teeth and depends for its operation upon the friction between the comparatively smooth surface of two rollers or pulleys. If corrugations were made in the surface to prevent slipping, a gear would result.

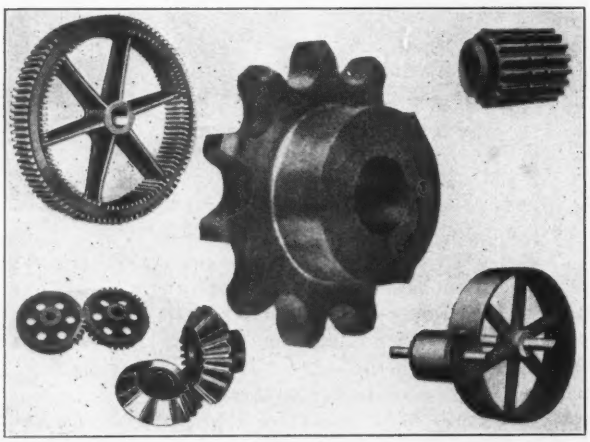


FIG. 4. SPECIAL FORMS OF GEARS. A, MORTISE GEAR WITH WOODEN TEETH. B, INTERMITTENT GEARS. C AND D, CHAIN SPROCKETS. E, FRICTIONS

Fundamentals of Common Gear Tooth Design

INVOLUTE FORM COMMONLY USED WITH STUB AND UNEVEN ADDENDUM TOOTH GAINING IN POPULARITY

ALTHOUGH the practices of modern, accurate gear design and cutting are complicated, the fundamentals are simple and easily understood. Starting with two cylinders of the same size, free to rotate, as shown in Fig. 1A, it is evident that if No. 1 is rotated one complete revolution, cylinder No. 2 will also rotate one revolution. If the diameter of cylinder No. 2 were twice that of No. 1, it would rotate but half a revolution, in other words, the angular velocity of the cylinders is inversely proportional to the diameters.

That is, it would be if the two surfaces did not slip

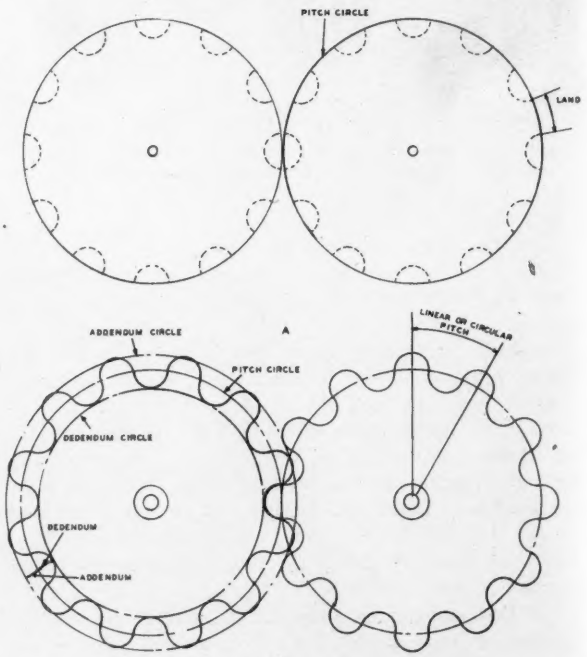


FIG. 1. FUNDAMENTAL DEVELOPMENT OF GEARS FROM PLAIN CYLINDERS

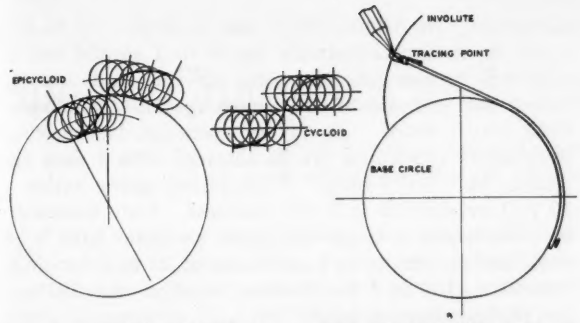


FIG. 2. DEVELOPMENT OF, A, THE EPICYCLOID AND, B, THE INVOLUTE CURVES

as they will do if any considerable amount of power is transmitted. To prevent this slipping action, grooves or corrugations are cut as shown dotted in Fig. 1A. If the part cut out is reversed and added to the solid parts, or lands, which remain the resulting cylinders would look like those of Fig. 1B. The parts added are called addendum and a circle drawn so that it just touches the outside of each of these parts is the addendum circle. The grooves are called dedendum and a similar circle drawn so that it just touches the bottom of each groove is the dedendum circle. The pitch circle is the circumference of the cylinder without teeth.

Such teeth would have excessive wear and low efficiency so that semi-circular teeth are not practical and the shape of the teeth must be changed so as to give a maximum rolling action of one tooth against another. In general two curves or tooth shapes have been used: the epicycloid, or two curve tooth and the involute, or single curve, tooth. The former is the curve traced by a point on a circle revolving on the circumference of a larger circle as shown in Fig. 2A while the latter is the curve traced by the end of a string as it is unwound from a circle as shown in Fig. 2B. The base circle from which these curves are developed is smaller than the pitch circle.

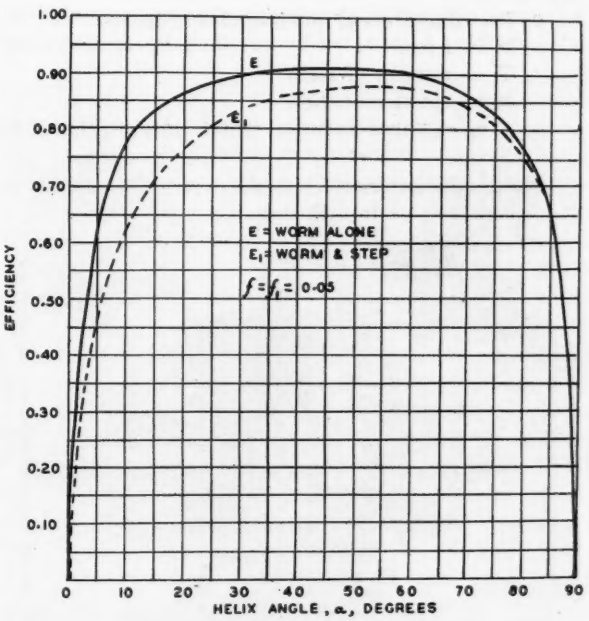
Standard 14½-deg. teeth give smooth operation and a minimum tendency of gear and pinion to push apart but with a small number of teeth the undercut necessary for clearance weakens the tooth somewhat and the 20-deg. stub tooth was introduced. Stubbing teeth means shortening the addendum and in this way increases the strength of teeth because of the decrease in leverage from tip to root. It also increases the percentage of rolling action but if carried too far tends to decrease wearing surfaces and thus shorten the life. Long addendum teeth simply means using a greater tooth length above than below the pitch line and is stronger than the standard form because it has more metal at the base. The mating gear in this case is cut with a corresponding short addendum and long dedendum.

Good Gears Have Small Friction Losses

MODERN HERRINGBONE GEARS SHOW EFFICIENCIES RANGING FROM 97 TO 99 PER CENT

FRICTION LOSSES in accurately cut, well spaced, properly lubricated gears are so low that this is seldom if ever a deciding factor in their selection for any particular service. As in any machine the work expended in friction appears in the form of heat and can be determined by finding the difference between the total work put in and the useful output. Cast gears are less efficient than cut gears, but the efficiency including bearing losses should range around 93 per cent for good spur and slightly lower, around 92 per cent, for good bevel gears. Cut teeth should run about 3 per cent higher.

Large gear systems with wood mortise teeth meshing with a cast-iron pinions, have been reported as 96.5 per cent while other tests on small 5 per cent nickel steel, case hardened pinion and gear drives showed efficiencies ranging from 91.4 to 96.6 per cent for low speeds and loading and 94 to 99.3 per cent at higher speeds and loadings. Efficiency of large single, double and triple



EFFICIENCIES OF WORM GEARING AS A FUNCTION OF THE HELIX ANGLE

reduction herringbone gear reducers as taken from a recent catalog of one manufacturer ranges around 98.9 to 99.44 per cent for single reduction units; 98.5 to 98.9 per cent double reduction units and 97 to 97.9 per cent for triple reduction units.

Efficiency of worm gearing varies with the helix angle of the thread, ranging from zero at 0 deg. angle up to a maximum at around 45 deg. and back to zero at 90 deg. This is evident because at 0 deg. angle the worm is a simple spur gear and at 90 deg. the worm teeth are at right angles to the gear axis. The accompanying curve shows the efficiency variation of worm gearing with a friction factor of 0.05. It will be seen that the most efficient angle is between 30 and 60 deg. although with accurately cut teeth good efficiencies can be obtained between 20 and 70 deg. or even smaller. Including the efficiency of the thrust bearing has the effect of increasing the most efficient angle as shown by curve E_1. In one particular case, this increase was from about 43 deg. for the worm alone to about 53 deg. for the worm and thrust bearing taken together.

Speed Ratios and Sizes of Gearing

RELATIVE SPEEDS DEPEND UPON DIAMETERS OF PITCH CIRCLE OR NUMBER OF TEETH

GEARS serve the double purpose of transmitting power and of changing speed. In a pair of gears, such as shown in the small sketch on the chart, it is a simple matter to show that two conditions must be met. Expressed mathematically

$$d + D = 2\,l \qquad (1)$$

and

$$\frac{d}{D} = \frac{N}{n} = \frac{t}{T} = R \qquad (2)$$

where

d, D = diameters of pitch circles in inches
n, N = r.p.m.
t, T = number of teeth
R = speed reduction
l = distance between center lines of charts in inches

Lower case letters refer to the driver and capitals to the driven member in each case.

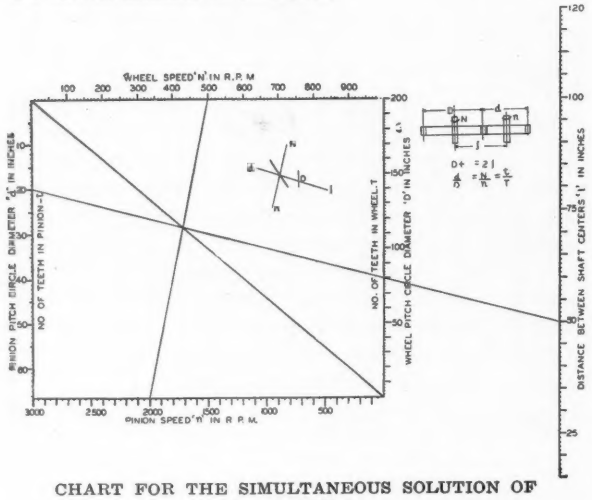

WHEEL SPEED 'N' IN R.P.M.
100 200 300 400 500 600 700 800 900
PINION PITCH CIRCLE DIAMETER 'd' IN INCHES
NO. OF TEETH IN PINION 't'
NO. OF TEETH IN WHEEL 'T'
WHEEL PITCH CIRCLE DIAMETER 'D' IN INCHES
DISTANCE BETWEEN SHAFT CENTERS 'l' IN INCHES
3000 2500 2000 1500 1000 500
PINION SPEED 'n' IN R.P.M.

CHART FOR THE SIMULTANEOUS SOLUTION OF EQ. 1 AND 2

Calculation of gear sizes to meet certain space and speed requirements requires the simultaneous solution of these two equations and to simplify this calculation the accompanying chart has been prepared. Knowing the necessary speeds of both shafts, a point can be located on the chart diagonal; a line drawn through this point and the distance between the shafts, l, gives directly the size of the gear and pinion.

As N ÷ n is merely a ratio, the chart can be used for very high or very low speeds by multiplying or dividing the desired values by 10. Furthermore, the left-hand part of the chart can be used alone to determine speed ratios when only the number of teeth are known. There is no relation between the diameter and tooth scales on the chart.

With straight tooth gears the pinion should not, in general, have less than 15 teeth; however, a smaller number is often necessary and in such cases unequal addendum teeth and large angles of obliquity are of advantage. No definite ratios can be given. Up to 4 to 1 can be used satisfactorily but 6 to 1 should not be exceeded because of noise and uneven loads on the pinion and because of the unmanageable gear dimensions which result. As far as operation is concerned satisfactory conditions can be obtained with a rack and pinion, an infinite ratio. With helical gears, ratios of 10 to 1 or even 15 to 1 are practical. Very accurately cut continuous herringbone gears, as taken from a recent catalog, run up to a maximum of 23 to 1 for single reduction; 130 to 1 for double reduction and 250 to 1 for triple reduction units.

Maximum speeds allowable at the pitch line depend upon the type of gear. For well pitched, well shaped cast-iron teeth the following speeds should not be exceeded:

Ordinary cast teeth.....1800 ft. per min.
Machine moulded teeth.....2000 ft. per min.
Helical cast teeth.....2500 ft. per min.
Mortise wheel teeth.....2500 ft. per min.

For cast-steel wheels, the foregoing speeds can be increased 20 to 25 per cent and for accurately cut teeth will run up to 3000 to 5000 ft. per min. or even higher.

With internal gears, another factor must be considered. If the pinion is large compared with the gear, fouling will result. One manufacturer states that the pinion should have at least 7 less teeth than the gear for 20-deg. stub teeth and 12 less teeth for standard 14½-deg. involute teeth.

THERE ARE TWO types of turbines, the impulse and reaction, so named after the method of transferring the energy from the steam jet to the turbine rotor. In the first, the jet itself is made to exert a push against the turbine blade as would a stream of water directed against a paddle wheel. The jet velocity is developed before it is made to impinge on the blade. In the reaction turbine, the backward push of the accelerating jet on the nozzle is utilized. This reaction of the jet on the nozzle is what makes the end of a free hose thrash about. The reactive force is present whether the nozzle is allowed to move or not. If the nozzle is free to move work can be done by it and this is what happens in the reaction turbine. The blades are formed in the shape of a nozzle and the reaction of the discharging jet of steam causes them and the rotor to revolve.

Impulse turbines are built in a variety of types or combinations usually referred to as single or multiple pressure and velocity staging. If all the possible heat energy is converted into velocity or kinetic energy of a jet in one stage or nozzle, it is known as a single pressure stage turbine. This velocity energy may then be converted into mechanical energy in a single row of blades known as a single velocity stage or in several rows of blades known as a multiple velocity stage.

Converting all the heat energy into velocity energy in a single stage results in high velocities, so that quite often only a portion of the heat energy is converted into velocity energy in the first set of nozzles. That is, just as a steam engine is compounded, so is the turbine, the steam is expanded to some intermediate pressure and this is known as multiple pressure staging. As with the single pressure stage turbine, the jet velocity between each pressure stage can be converted into mechanical energy in one or more velocity stages.

Speed Changers and Variators for Shaft Drives

HIGH RATIOS OF SPEED TRANSFORMATION WHICH CAME WITH TURBINES AND MOTORS ARE ACCOMPLISHED BY GEARED UNITS

WITH THE advent of high-speed motors and steam turbines as direct drives for industrial machinery came the need for convenient, compact and efficient means of changing the speed of the driving shaft to suit the much slower driven shaft. Motor and turbine speeds as high as 3600 r.p.m. are not uncommon and speed reductions as high as 500 to 1 are sometimes required. Speed ratios of as high as 7 to 1 are handled efficiently by belting, chains or gearing, even ratios of 12 to 1 are obtained by similar means with less efficiency. Higher ratios, however, are best handled by some form of speed-reduction gear unit which is especially designed for a particular service.

Speed changing gear units may employ any one or a combination of the following four types of gears;

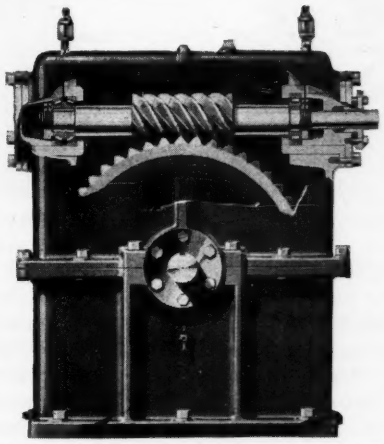


FIG. 1. WORM GEAR REDUCER WITH ROLLER THRUST BEARINGS

worm, spur, bevel and herringbone. These gears are inclosed in an oil tight housing which supports the bearings and the extending shafts are connected by couplings, preferably of the flexible type, to the driving shaft of the motor and the driven shaft of the machine. Their horsepower capacity varies with the design and materials used in construction ranging from a fraction of a horsepower to as high as 1300 hp. The usual horsepower ratings given are maximum and in making selections allowances must be made for shocks and starting strains to which the unit may be subjected. Efficiencies will vary with the design, construction and workmanship used in the manufacture of the unit but it is generally recognized that the greater the speed change the less will be the efficiency. With the modern practice of running the gears in oil and the use of ball and roller bearings, efficiencies are high.

WORM GEAR REDUCTION UNIT

One of the earliest types of gearing used for high ratios of speed reduction consists simply of a screw meshing with a toothed wheel, each revolution of the screw shaft advancing the wheel the distance of one tooth in its revolution. This is known as worm gearing and, although it has been known and used for centuries, it remained for the twentieth century engineers to develop its efficiency to a point comparable to other forms of gearing.

Worm gears have the advantage of a high ratio of speed reduction. They are essentially right-angle offset drives, that is, the worm shaft and the wheel shaft are at right angles to each other but in different planes. The unit may be designed for off-set parallel shafts by the

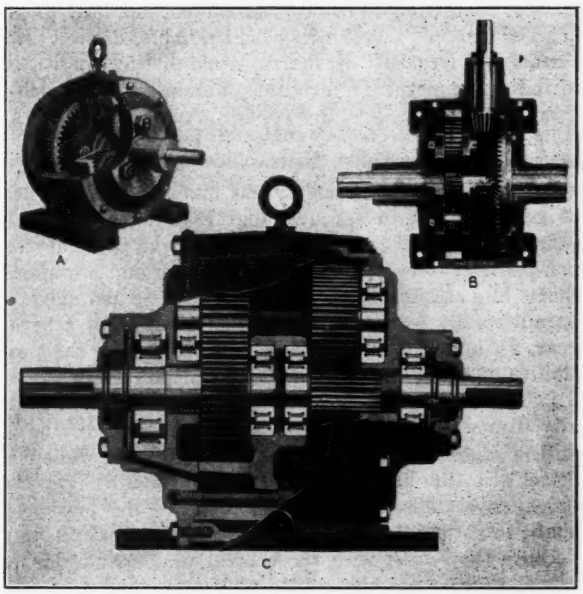


FIG. 2. TYPES OF SPUR GEAR SPEED REDUCERS

use of bevel gears but each additional gear wheel cuts down the efficiency of the unit. Worm gears are seldom used as speed increasers, since, for this purpose, the efficiency is low and power available is extremely small.

Worms in a modern first-class speed reducing unit are usually integral with an alloy-steel shaft with the threads hardened and ground. Bearings of ball or roller construction hold the worm shaft rigidly in place as extremely accurate alinement is positively essential to satisfactory operation. The rear bearing is usually designed to take the full thrust load of the shaft as well half the radial load, the other half of the radial load being carried by the forward bearing.

The gear wheel usually consists of a chilled, cast-bronze rim shrunk on and pinned to a high-grade, cast-iron center. For efficient operation these units must run true to the helical angle of the gear so that vibration must be eliminated by balancing the revolving parts. These gears are, as previously stated inclosed in an oil tight housing filled with oil of a grade suitable to the

character of the load. The oil not only minimizes the friction but conducts the heat due to friction losses to the radiating surfaces of the housing.

Commercial units are built in horsepowers ranging from 0.13 to 300 for driving speed from 100 to 300 r.p.m. and in shaft speed ratios from 4⅜ to 1, to 75 to 1. Higher ratios are, of course, possible but above 70 to 1 in a single reduction the efficiencies drop rapidly. With double reduction, using two worm gears in series reductions as high as 10,000 to 1 are made possible. Manufacturers have standard units employing this type of gearing for right-angle horizontal shaft drive, right-angle drive with one shaft vertical and, with an additional bevel gear, parallel shaft drive.

In ordering worm reduction gear units, the purchaser should specify the horsepower of the driving motor, turbine or driven shaft; the actual horsepower required by the driven machine; speeds of the worm and gear shafts; directions of shafts rotation; continuous operating time or program of the unit; character of the service, describing the source of power and load to be handled; submit sketch of space, available, desired and permissible locations of shafts; atmospheric conditions including temperature variations, humidity, acid fumes, character of dust.

Reduction Units Employing Spur Gears

Among the most common and highly efficient types of gearing used in speed changing units is the spur gear which can be constructed in either the planetary or non-planetary arrangement with the high and low-speed shafts in a straight line. The shafts can be arranged in parallel offset positions or, with the addition of a bevel gear, an angle drive may be constructed with the possibility of using one shaft in a vertical position.

Planetary units consist of spur gears or idlers radially disposed about a central pinion and in turn mesh with a stationary internal gear. The central pinion is attached to the high-speed shaft while the idlers revolve on studs attached to a spider keyed to the low-speed shaft, thus the idlers revolve around their own axes and, because they mesh with the central pinion and the internal gear, cause the spider to revolve and turn the low-speed shaft. This type of reducer is suitable in single reduction for ratios between 4 to 1 and 8 to 1, below or above which the non-planetary arrangement is more suitable, for it becomes unnecessarily large for higher ratios and at lower ratios the idler assembly revolves at an excessive speed with resultant friction loss and heating.

Units of the non-planetary type usually consist of spur gears radially disposed about a central pinion, each of the spur gears being keyed directly to pinions which turn in mesh with a central gear mounted upon the slow-speed shaft. Another type of non-planetary gear has the same relative location of gears as the planetary arrangement but the idler assembly is held stationary while the internal gear, keyed to the slow-speed shaft revolves in a direction opposite to that of the high-speed shaft. Spur gear units are therefore capable, with modifications in design, of a wide variety of applications in industry.

With the non-planetary type, speed ratios as low as 1 to 1 and as high as 300 to 1 are practicable. Double reduction arrangements make possible ratios as high as 500 to 1 in commercial service. Spur gear units are built in standard capacities ranging from 1 to 225 hp. and for speeds of 1800 r.p.m. down.

Herringbone Reduction Units

Gears of the herringbone type are the most recent to be developed; they are high in efficiency, silent in operation and applicable to the transmission of large powers with gears for intermediate and low powers becoming more common as their advantages become more generally known, notwithstanding their higher cost. Single reduction herringbone gear units do not possess the shaft in line features of the spur gear nor the right-angle drive of the worm gear. Single reduction ratios as high as 7 or 8 to 1 are commonly used while with double reduction, ratios up to 60 to 1 are available in standard units and higher ratios are obtainable with triple reduction. Units of this type are built for horsepower capacities up to 1400 and for speed up to 1800 r.p.m.

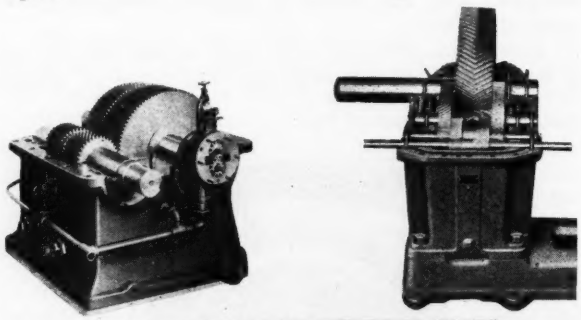


FIG. 3. HERRINGBONE REDUCING GEARS

In construction, the single reduction gear unit consists of a pinion and one gear mounted on parallel shafts, usually supported by frictionless bearings with the whole inclosed in an oil tight casing. Two distinct types of double reduction units are manufactured. In one, two sets of herringbone gears are mounted in series while, in the other, the two halves of the first gear are separated sufficiently on the shaft to permit the second gears to be placed between them. This latter arrangement distributes the bearing strains more evenly and permits a more compact unit than with the first type. Units are also made up with the addition of a bevel gear which forms a speed changer suitable for right-angle drive.

Wherever speed changers of the type described here are used, they must be accurately alined with the elements they connect and shaft connections should be made with flexible couplings as misalinement is disastrous to satisfactory operation of any gear box. Where possible, the speed changing unit should be mounted on the same bed plate as the driving and driven elements and to relieve the strain on the gear shaftings, any overhung loads should be supported by an overhung bearing. In operation, lubrication is of extreme importance as friction creates heat which must either be dissipated or absorbed by the unit to raise its temperature and extreme temperatures will cause sufficient expansion to destroy the proper meshing of gears. This subject of gear lubrication is treated elsewhere in the issue.

In many industrial applications, it is essential to secure variable speeds of operation. In some instances,

this result can best be obtained by a variable speed motor or engine but in other instances power is secured from a constant speed shaft and to meet this situation several mechanisms have been devised.

One of the early types, still used to some extent, consists of a disk upon the face of which a friction wheel contacts at various adjustable distances from the axis of the disk. The friction wheel is attached to a shaft through a flexible coupling, which permits adjustment of the pressure between the friction wheel and the disk, and sleeve to permit play across the face of the disk. Such a device is seldom used except for small powers

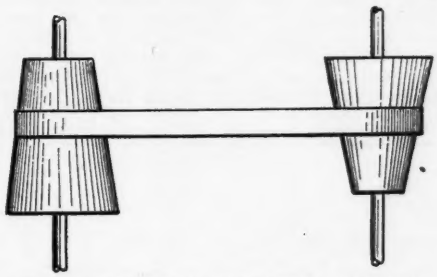


FIG. 4. BELT AND CONE PULLEY DRIVE

although it has been applied instead of shift gears on automobiles. This is necessarily an angle drive but it has the advantage that the rotation of the shaft can be reversed by adjusting the friction wheel to contact on opposite sides of the center of the disk and an infinitely fine adjustment of speed can be obtained within the limits of the design.

Another variable speed device is the cone-pulley belt drive frequently seen in paper and textile mills. This drive is illustrated diagrammatically in Fig. 4 from which it will be seen that shifting the belt up or down will cause a variation in the speed of the driven shaft if the driving shaft runs at constant speed. This type of drive is a source of trouble, particularly with cones of extreme taper when even narrow belts are twisted out of shape and are short lived. In order to keep the belt running in the proper location, a shifting fork must be employed which also causes excessive wear. Crossing the belt causes the long edge of the belt always to be on the high side of the pulley and results in better operation. For this purpose the belting used should be of special design for the particular drive.

One of the most successful devices for securing variable speed from a constant speed source consists of two parallel shafts upon each of which are mounted two cone-shaped disks with their apexes facing each other

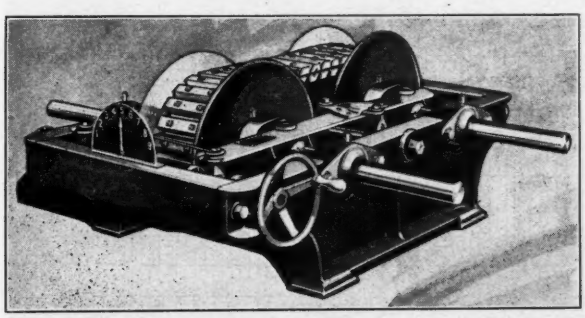


FIG. 5. VARIABLE SPEED V-BELT DOUBLE CONE DRIVE

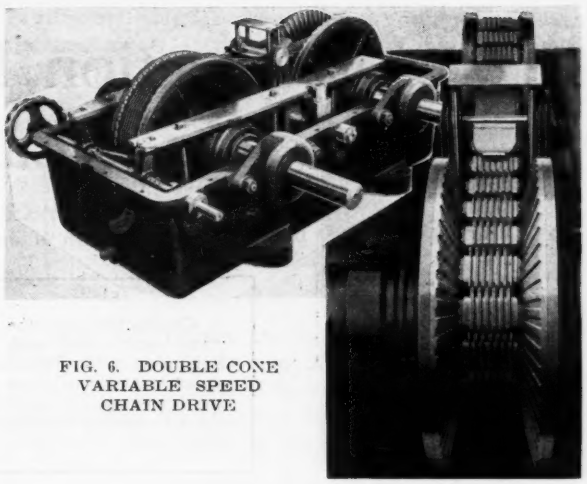


FIG. 6. DOUBLE CONE VARIABLE SPEED CHAIN DRIVE

thus forming a pulley with a V-shaped face. The disks are so mounted on the shafts and connected by control mechanism that as the disks on one side are brought closer together those on the other shaft are separated an equal amount. A special V-type belt with the contact surfaces along the edges is used, its running position on the face of the disks being governed by the distance between the faces of the disks. In this way the effective diameters of the pulleys are changed to meet the speed requirements. This device gives a smooth transition from one speed to another with an infinite choice of speed ratios within the limit of the design. Ratios are from 2 to 1 up to 16 to 1 as the minimum and maximum.

Working on a similar principle, another design of variable speed changer uses cones with grooved faces and a specially constructed chain built up of bundles of adjustable laminated steel sheets that form themselves into teeth to match the grooves in the cones. Such an arrangement gives a positive rather than a friction drive.

Minute gradations of speeds are secured by the device shown in Fig. 7 which consists essentially of three rollers, resembling closely the form of a double cone, which roll around the outside of two inner races and around the inside of two outer races; the inner races are rotated by the input or constant speed shaft while the outer races are stationary. The rollers are, therefore, caused to move in planetary fashion about the axis of the machine and at a slower speed than that of the inner races. The speed change is effected by moving axially the outer and inner races, thus varying the effective diameters in such a way as to secure all the speed ratios between the design limits of the unit.

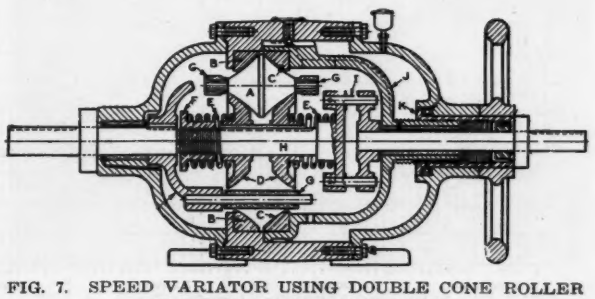


FIG. 7. SPEED VARIATOR USING DOUBLE CONE ROLLER BETWEEN ADJUSTABLE RACES

Power Production, Distribution and Use in a Large Industrial Plant

ECONOMIES IN STEAM GENERATION, CURRENT, HEAT SERVICE, COMPRESSED AIR ELECTRICAL AND MECHANICAL TRANSMISSION AND DRIVES. BY DAN GUTLEBEN

Graduating from the University of Nebraska, Dan Gutleben worked on beet sugar plant construction with Oxnard Construction Co. and afterward with the Dyer Co. Beginning with 1907, he built buildings, bridges and radio stations in Alaska and sugar factories in Utah and Idaho, with Gutleben Bros., contractors. Since 1921 he has been engineer with Pennsylvania Sugar Co. and is now in charge of that department, designing buildings and plants, much of the machinery being his original design.

FOR A TYPICAL 24-hr. day's work, the power plant of the Pennsylvania Sugar Co. produces 10,000,000 lb. of steam at 10 lb. pressure. Of this 5,400,000 lb. goes to the accumulator and is reduced to 80 lb. pressure through reducing valves for the vacuum pans, 400,000 lb. goes to the By-Products plant through reducing valves at 60 lb. and 4,200,000 lb. goes to engines and pumps for power production, delivering exhaust steam at 12 lb. pressure for process work. The equipment is 13 Stirling and B. & W. boilers aggregating 7000 hp. rating, provided with Taylor stokers, Green economizers and steam-driven stoker engines, blowers and feed pumps. The newest of the boilers is 8 yr. old.

In 1929 the cost of converting one short ton of coal into steam was as follows:

Coal	$4.42
Repairs and Maintenance	0.45
Labor	0.45
Power	0.05
Depreciation (Arbitrary)	0.35
General Overhead (Arbitrary)	0.10
Total	$5.82

Dividing the total coal consumption (118,000 t. in 1929) by the total steam production (i.e. the aggregate of the boiler flow meter readings) gives 91.7 lb. of coal per 1000 lb. of steam, which at $5.82 per ton, is a cost of $0.27 per 1000 lb. of steam.

In the power plant are a 6,000,000-gal. per day Corliss-engine-driven raw water pump, sundry direct-act-

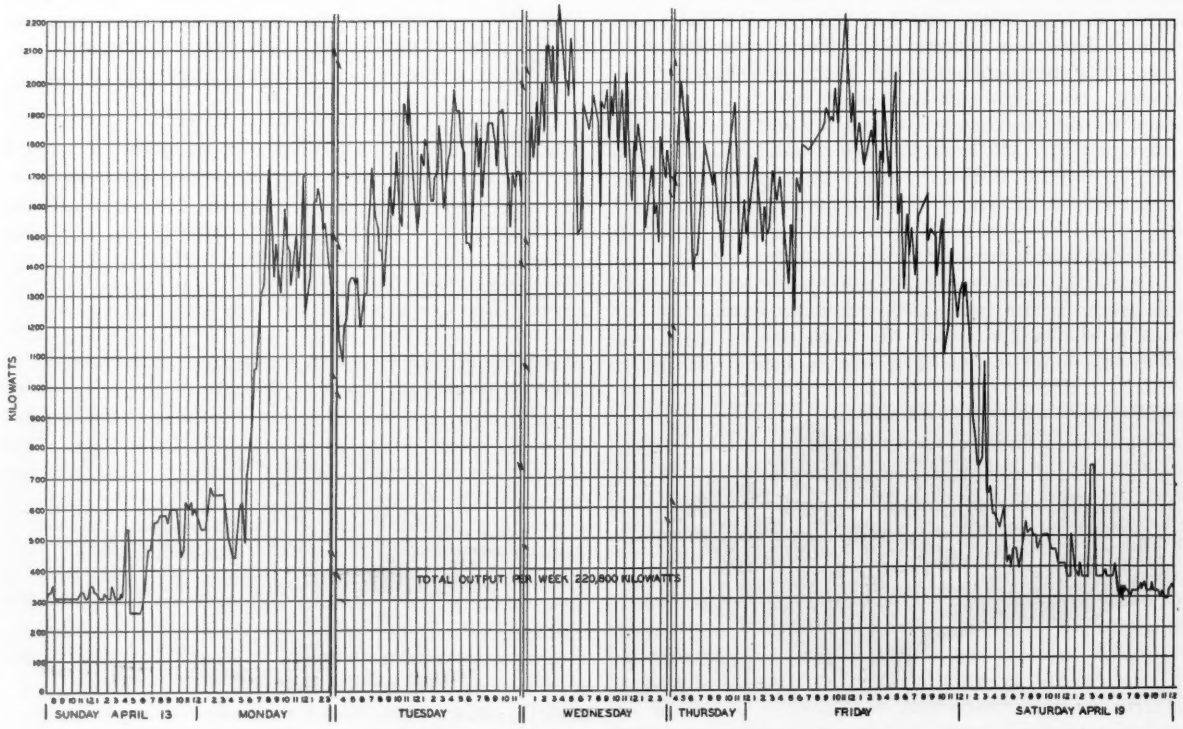


FIG. 1. LOAD CURVE FOR PART OF A TYPICAL WEEK

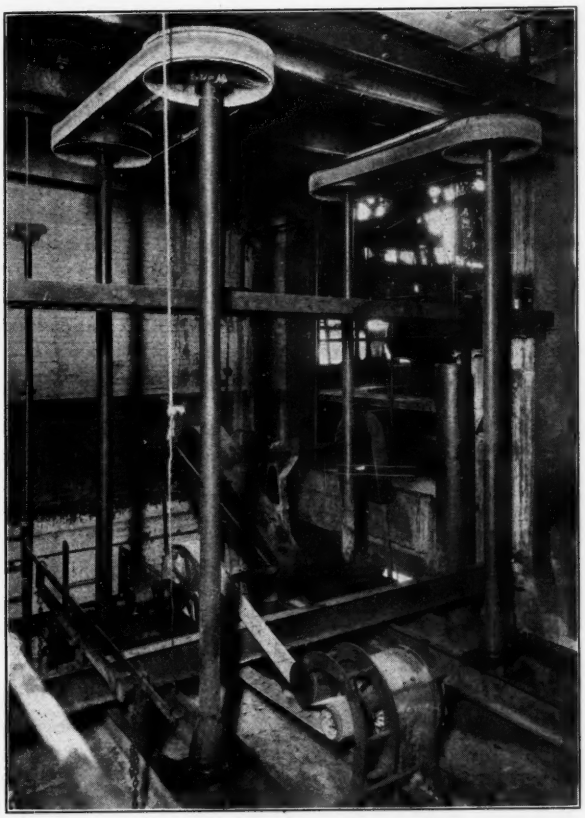


FIG. 2. ONE MOTOR A DRIVES 4 STIRRERS, A CLASSIFIER BELOW, AND A DORCO PUMP, FROM ONE JACK SHAFT

ing steam pumps and 5 Corliss-engine-driven, 230-v. d.c. generator sets, which latter aggregate 3000 kw. The usual output is 2000 kw. per hour (1,000,000 kw-hr. per month) but, on account of demand fluctuations that reach more than 500 kw. in one-half hour's time, Fig. 1, all of the generators usually operate. This surplus generator capacity to cover the peak requirements causes no appreciable loss of steam except for occasional short periods when, through irregular plant operation, some exhaust steam is wasted to the atmosphere. No apparatus is available for ascertaining the difference between the amount of 145 lb. of steam going into the engines and the 12-lb. steam exhausted. It is assumed, however, that the loss is not more than 5 lb. of steam per kilowatt-hour.

The cost of power per 1000 kw-hr. is then:

Steam, 5000 lb. at $0.27	$1.35
Labor	0.92
Repairs, Maintenance and Oil	1.00
Depreciation and Overhead	2.00
Total	$5.27

Labor and repairs and maintenance cost were obtained by dividing the total 1929 cost by the total output of 12,000,000 kw-hr. In the case of the depreciation and overhead, the arbitrary figure of 10 per cent of the plant cost was divided by the output.

Electric Transmission

Direct current is produced at 230 v. To guard against interruptions in the process, a considerable number of standby motors and machines are required, the total number and horsepower being as follows:

	No.	Hp.
For Operating	622	8428.5
Standby	38	1250.0
Surplus	123	1951.0
Total	783	11,629.5

Maintenance and repair are high for d.c. motors, especially in a plant where they run under uncomfortable conditions including air laden with sugar dust, moisture, coal and char dust. In 1929 this cost, covering the operating and standby motors, was as follows:

	Total	Per motor	Per Hp.
Labor	$14,350	$21.74	$1.48
Materials	17,146	25.96	1.77
Total	$31,496	$47.70	$3.25

Ten per cent of the labor is general shop overhead and about 10 per cent of the item of material is for new motors replacing those worn out. All of these motors have antifriction bearings. They are standardized as to make and the speeds are usually 850 and 1150. Variable speed motors are used in considerable numbers and frequent changes are made in motor speeds as process revisions make desirable, this being an outstand-

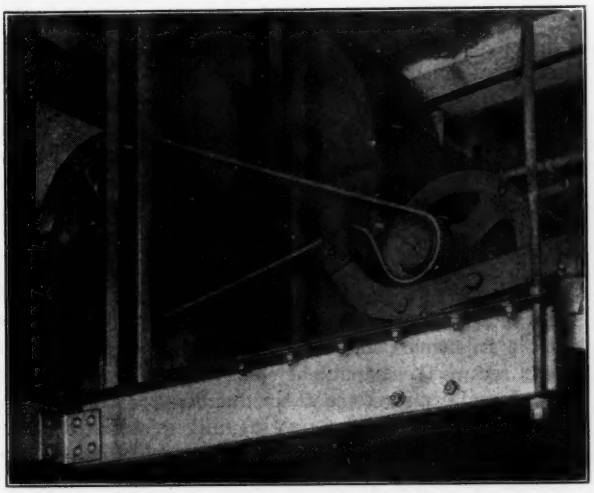


FIG. 3. ELEVATOR HEAD GEAR IN BOX

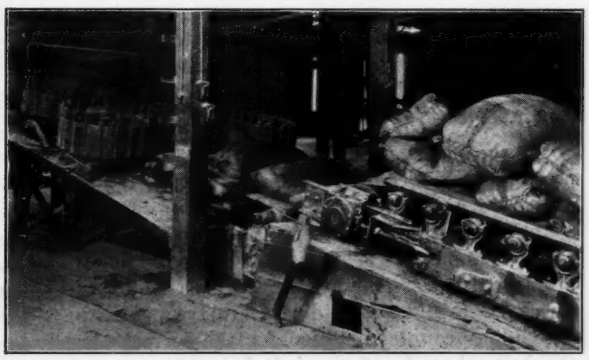


FIG. 4. FOOT OF 60-IN. CONVEYOR. BALL BEARING ROLLERS AND TAKE-UP BOXES

ing advantage of direct current. It costs much less to keep the motors clean than to make the repairs which result from uncleanliness. The ball bearings keep the oil out of the windings and dust is removed with the aid of an air blast either from a portable blower or via hose from the compressed air main.

In recent years the former tendency to be too liberal in motor size has been changed. Smaller motors have taken the place of larger ones, with a noticeable decrease in total power consumption. Fluctuations in power consumption, as shown on Fig. 1, are rather violent but efforts to reduce them are meeting with no success.

For driving centrifugal pumps, motors are almost invariably direct connected. In some cases it seems advantageous to drive several machines from one motor, as in Fig. 2.

Some years ago a general revision was started in all of the drives in the plant. Ball bearings replaced sleeve and grease bearings. The drives include belts, Texropes, standard steel roller chains, silent chains, open gears and worm and spurgear reducer units.

Gear Belt and Chain Drives

Heavy sugar elevators have large gears on the headshafts, 1½-in. pitch by 6-in. face. The countershaft is belted to the motor or to a second countershaft, Fig. 3. Some of these were originally geared direct to the motor. Chains on these elevators had about 3 yr. life and were troublesome. When the gears were replaced with belts, the chain vibration, due to a long pitch on a comparatively small diameter sprocket, was reduced and the life of the chains was doubled. The standard elevator chain is now a steel roller chain, SS39+. In some cases, a sprocket for a Manufacturers' Standard 2-in. pitch steel roller chain is used on the headshaft instead of a gear and, for lighter elevators, a 1-in. pitch sprocket is used. These are quieter than gears.

Headshafts of most belt conveyors are driven by steel roller chains for the first reduction, followed by short-center belts with ball bearing idlers. These are quiet and speeds can easily be changed. Two 60-in. belts, Fig. 4, that carry 325 lb. bags and start and stop rather frequently are driven by means of spurgear reducers. Small portable conveyors and bag pilers are driven by worm-gear reducing sets with the worm-wheel shaft extended for headshafts. The same drive is used for manlifts (i.e., employes belt elevators). These reducers are used where compactness is required. All of these are selected with a large factor of safety; they are the highest first-cost drives in the plant and in the six years that they have operated there has been no repair expense.

In the arrangement of group drives, it is frequently possible to omit countershafts. A crusher is direct connected to a motor and the motor half of the flexible coupling is widened to serve as a pulley to drive the elevator that feeds the crusher. A group of stirrers, a pump and a classifier are driven by a motor without a lineshaft, Fig. 2. Belt drives are frequently provided with idlers counterweighted for the correct tension for the belt, the life of the belt being increased by this device.

Antifriction Bearings

For combined radial and thrust bearings for reversible scroll conveyors, deep-groove, double-row ball bearings are used, mounted in trunnion-supported housings made of steel tubes, Fig. 5. These are easy to build and require no precise machine work as do ball and socket housings. A similar device, using a plain rigid ball thrust bearing is used at the end of mechanical filter shafts, where there is only a thrust strain without the radial. The trunnions are easily supported in vertical posts.

In power transmission it is convenient to standardize on the parts. It is remarkable how the number of

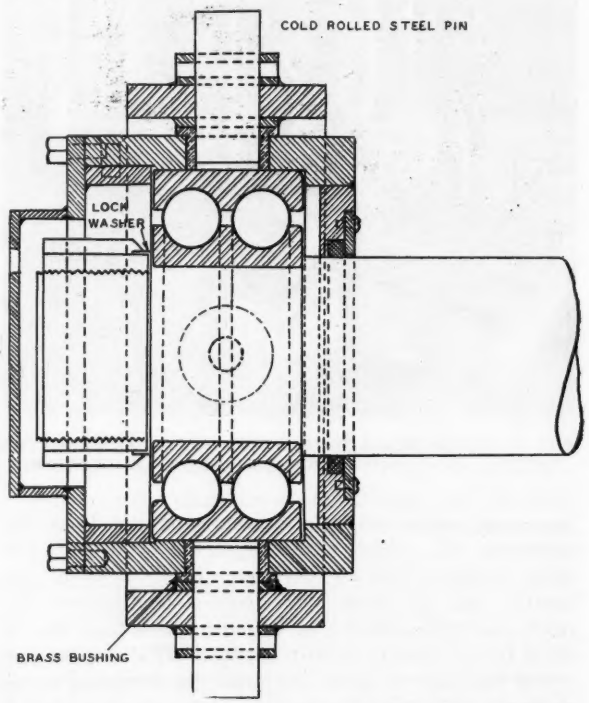


FIG. 5. REVERSIBLE THRUST BEARING FOR SCROLL CONVEYORS

varieties of gears and chains can be reduced. In the Pennsylvania Refinery are seven sizes of sprockets for 1-in. pitch, manufacturers' standard steel roller chains; four pairs of cut spur gears; four pairs of bevel gears and so on. In all cases, the hubs are made large enough to bore to any of the sizes of shafts used. Also the hubs are symmetrical about the center line so that wheels can be reversed in order to extend their life. The lists of standard gears, sprockets, chains and parts give, in addition to the place used, the price, which is convenient information for the designer.

Revision and improvement of the equipment provides activity for the maintenance gang and makes their work a full time job. Eventually, their own improvements reduce the amount of operating and repair work needed and thus reduce their numbers. Modern tools such as a turret lathe, universal mill, grinders, electric welders and high-speed lathes pay dividends in the maintenance shop just as they do in the commercial machine shop.

Calculating Heat Losses from Buildings

RULE OF THUMB METHODS GIVE SATISFACTORY RESULTS FOR AVERAGE CONSTRUCTION BUT MUST BE MODIFIED TO MEET UNUSUAL CONDITIONS

WHEN PLANNING to heat buildings consideration must be given to heat losses through the walls, glass, roof and floor; leakage of cold air into the space to be heated, whether this be through doors, cracks or ventilation equipment; heat supplied by people, lights, motor and machinery; the difference in temperature between the outside and inside and the wind velocity.

Detailed calculations can be divided into six steps: determination of the inside temperature; determination of the minimum outside temperature to be designed for; determination of the heat transmission coefficient for the wall or walls to be used; determination of wall areas;

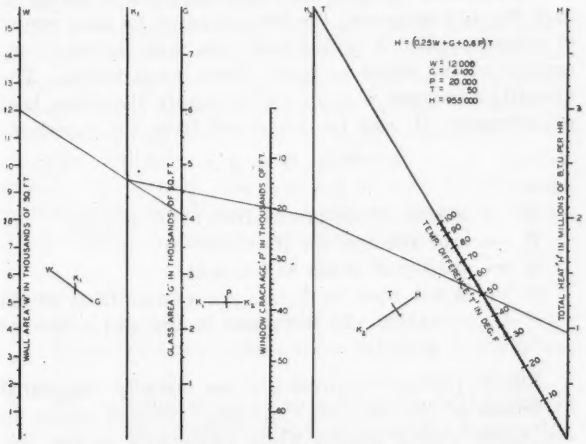

H = (0.25W+G+0.6P)T
W = 12 000
G = 4 100
P = 20 000
T = 50
H = 955 000
WALL AREA 'W' IN THOUSANDS OF SQ. FT.
GLASS AREA 'G' IN THOUSANDS OF SQ. FT.
WINDOW CRACKAGE 'P' IN THOUSANDS OF FT.
TEMP. DIFFERENCE 'T' IN DEG. F.
TOTAL HEAT 'H' IN MILLIONS OF B.T.U. PER HR.

CHART FOR DETERMINING HEAT LOSSES FROM BUILDINGS

calculation of heat losses from each surface; calculation of heat requirements of air infiltration, leakage and ventilation.

Temperatures to be maintained inside depend upon the service for which the building is to be used. Good practice fixes these temperatures at about the following values.

Foundries	50 to 60 deg. F.
Machine shops	60 to 65 deg. F.
Stores, factories	65 deg. F.
Schools, residences	70 deg. F.
Public buildings	68 to 72 deg. F.
Hospitals	72 to 75 deg. F.

Other factors in the calculation depend upon local conditions and the type of wall construction used. Outside temperatures and wind conditions to be expected can be obtained from the weather bureau records. In temperature localities where the lowest recorded temperature occurs infrequently, calculations can be based on temperatures of say 10 deg. above the lowest recorded. Where protracted cold spells are frequent, however, it is best to use the lowest recorded temperature.

Wind increases heat losses in two ways: by increasing the heat transmission through walls (relatively more important for poor walls) and by increasing air infiltration through walls and cracks. Cold air entering the room must be heated to the desired temperature so that heat losses are directly proportional to the infiltration.

Approximate rules based on average construction and ratio of wall and glass surface have been developed and give satisfactory results in cases to which they apply. For unusual conditions, more detailed calculations as outlined above must be used. Harding & Willard propose an adaptation of the earlier Carpenter rule based on an average heat transmission of 0.25 B.t.u. for walls and 1.0 B.t.u. for glass and considering only outside walls. This can be stated as

$$H = (0.25\ W + G + 0.6\ P)\ T$$

where

H = total heat to be supplied B.t.u. per hr.
P = total window crack length in ft.
W = wall surface in sq. ft.
G = glass surface in sq. ft.
T = difference between inside and outside temperature in deg. F.

This equation is of course based on a number of assumptions which render its application for accurate calculation in unusual conditions approximate although, when modified by one familiar with design, it will produce satisfactory results. As an approximation or as a check on more detailed calculations, such practical rules are of great value. The equation given above is comparatively simple but its value lies in its ease of application and to facilitate calculations the accompanying chart has been prepared.

Determination of Direct Radiation Needs

SURFACE AND STEAM REQUIREMENTS FOR HEATING ELEMENTS PLACED IN THE ROOM

HAVING CALCULATED the heat input necessary to maintain the desired temperature in the space under consideration, the next step is the determination of the best method of supplying this heat, i.e., steam, hot water, electricity or warm air. Heating elements using steam are commonly classed as direct or indirect radiators depending on their design and location. Direct radiators are placed in the room to be heated and transmit heat both by radiation and convection. Indirect heaters are placed outside of the room to be heated, or built, so that the heat is transmitted entirely by convection.

In order to calculate the radiating surface necessary to supply the desired amount of heat, it is necessary to know how much heat one square foot of surface will transmit under the condition where it will be installed. Heat transfer from the heating media in the radiator to the outside air takes place in three steps; from the heating media to the inside metal surface; through the metal to the outside surface; from the outside surface to the surrounding air. As the metal wall is a good conductor and the inside resistance is smaller than the outside resistance, the temperature of the metal radiator approaches that of the heating media whether it be steam or water.

This heat then leaves the outside surface in one of two ways; by radiation in which the heat is transmitted in straight lines at a rate proportional to the difference of the fourth power of the relative temperatures; by convection which is primarily dependent on the velocity of the air sweeping over the radiator surface.

Total heat transmission from direct radiation will be the sum of the radiation and convection losses. This total emission as determined from experiments by the A.S.H.&V.E. can be written as:

$$K = S R \left[\left(\frac{T_s}{100}\right)^4 - \left(\frac{T_r}{100}\right)^4\right] + C\,(t_s - t_r) \qquad (1)$$

= radiation loss + convection loss

Where

- K = B.t.u. emitted per square foot of surface per hour per deg. temp. diff.
- S = surface factor (0.104 to 0.157)
- R = form factor of radiator (See Eq. 2)
- C = convection factor of radiator (See table)
- t_s = temperature of steam, deg. F.
- t_r = desired room temperature, deg. F.
- T_s = absolute steam temperature t_s + 460
- T_r = absolute room temperature t_r + 460

Many factors enter into the determination of the actual emission. The factor S depends primarily upon the surface condition of the metal or on the paint used. It ranges from 0.157 for a clean cast-iron radiator down to 0.104 for an aluminum paint finish, which is the poorest radiator of the commonly used surface coverings. Another matter of importance is the factor R which may be expressed as the ratio of the enveloping surface to rated surface. In commercial radiators, some parts screen radiation from other parts and thus cut down the total heat radiating surface, the factor R is intended to take care of this condition and can be calculated from

$$R = \frac{2\,W\,L\,H}{RS} \qquad (2)$$

Where

- R = form factor of Eq. (1)
- W = width of radiator in feet
- L = length of radiator in feet
- H = height of radiator in feet
- RS = rated surface of radiator in square feet

Tall radiators do not have as great convection losses as short radiators and the factor C varies with the height of the radiator about as follows:

Up to and including 23 in. high, C = 1.096
26 in. high, C = 1.089
32 in. high, C = 1.069
38 in. high, C = 1.028
45 in. high, C = 1.008

Practically much less than half of the heat given off is by radiation. General conclusions that can be reached are that single column and low direct radiators have a higher coefficient of transmission than multiple column or high radiators; furthermore, dull and dark finish radiators radiate more heat than those with bright or polished surfaces while the position of the radiator in reference to walls, covers and enclosures is extremely important, the A.S.H.&V.E. code showing a spread of from 75 below to 110 above standard for different arrangements. (In this code, equivalent direct radiation is defined by the minimum heat emission in B.t.u. per hour divided by 240. Thus in Eq. 3 below when K = 240, T is in square feet of equivalent direct radiation.)

Knowing the heat emission K, per unit of surface, the total surface necessary can be calculated from

$$T = H \div K \qquad (3)$$

where

- T = total radiating surface in square feet
- H = total heat requirements in B.t.u. per hour
- K = total emission per square foot in B.t.u. per hour (from Eq. 1)

The heat H, which must be emitted from the surface T must be supplied in the form of steam. Inasmuch as the water of condensation leaves the radiator at the temperature corresponding to the saturation pressure of the steam, and because the steam supplied is rarely if ever dry and saturated, the heat given up by each pound of steam supplied is considerably less than the total heat content of the steam as found from steam tables. The quantity of steam W required to supply the given heat requirements H, can be calculated from the equation:

$$W = H \div x\,r \qquad (4)$$

where

- W = weight of steam required in lb. per hr.
- H = heat required in B.t.u. per hr.
- x = quality of steam as per cent
- r = latent heat in B.t.u. per pound from steam tables. If the steam is dry and saturated x = 1.

Steam piping requirements are usually calculated by means of the Babcock formulas discussed earlier in the steam piping section while condensate return line sizes can be calculated by the same methods as used for figuring hot-water heating system pipe sizes as explained in a later article.

An inspection of Eq. 1 shows that the heat emission K for a given radiator can be increased by increasing the steam temperature. This can be accomplished by increasing the pressure of the steam in the radiator. For instance, increasing the steam temperature from 213 (0 lb. gage) to 250 deg. F. (approx. 15 lb. gage) would increase the first part of Eq. 1 about 41 per cent and the second part about 27 per cent, increasing the total emission K about 30 per cent, the exact value depending upon the type of radiator used and the relative value of the radiation and convection losses.

Increasing the pressure would, however, increase the steam requirements of the system somewhat because the value r in Eq. 4 decreases with pressure from 920.2 B.t.u. at 212 deg. F. (0 lb. gage) to 945 B.t.u. at 250 deg. F. (approx. 15 lb. gage), a decrease of about 2.5 per cent. Actually the change may not be quite as much as this because the condensate in the return system radiates some heat to the surrounding walls and the returns may show little or no difference in temperature. Increase in pressure is accompanied by a decrease in volume which more than compensates for the increased steam quantity and at the higher pressure the same size pipe can handle considerably more steam with the same pressure loss.

Indirect Heaters

INDIRECT HEATERS IN WHICH THE HEAT TRANSFER IS ENTIRELY BY CONVECTION ARE POPULAR

INDIRECT RADIATORS and heaters warm a room or building by heating a comparatively small quantity of circulating air to a temperature higher than the temperature that must be maintained in the room. Heat transfer from the heater to the air is, for practical purposes, entirely by convection and, in most indirect heaters, the transmission coefficient is increased by forced circulating of the air at high velocities.

Many different types are used to meet different heating, ventilating and process requirements. Most of them have forced circulation although gravity indirect heaters where the air is circulated by gravity alone are widely used particularly for domestic heating. This article, however, will consider only those using forced circulation and commonly called blast heaters, tempering coils, reheaters, fan systems and unit heaters.

In selecting heaters of this type, the following points must be considered: total heat requirements, air volume required, velocity through heater, loss in air pressure through heater; amount of heating surface. Total heat requirements as determined from heat losses from the room or building has been discussed in a previous article. To supply this amount of heat to the room requires the circulation of a certain quantity of air which can be calculated from the equation

$$H = 0.24\ M\ (t_1 - t_e) \qquad (1)$$

where

M = weight of air circulated in pounds per hour
H = total heat losses from building in B.t.u. per hour
t_1 = temperature of air leaving the heater deg. F.
t_e = temperature of air entering the heater deg. F.
0.24 = B.t.u. required to raise 1 lb. of air 1 deg. F.

If the air is recirculated t_e is equal to the mean room temperature t_r. If, however, heating is combined with ventilation and the entire amount of circulated air is drawn from the outside, it is apparent that more heat must be added to bring the temperature from t_a (atmospheric temperature) to mean room temperature t_r. This additional heat will be

$$H_1 = 0.24\ M\ (t_r - t_a) \qquad (2)$$

and the total heat input to the heater must be increased from H to $H + H_1$. In some cases, part of the air will be recirculated and part taken in from the outside, in other cases heating requirements may be split part being supplied by direct radiation and part by indirect. In these cases, proper values of H and M must be inserted in Eqs. 1 and 2 as dictated by individual conditions.

Velocity through the heater is generally given in manufacturers tables as being measured at 70 deg. F. and has a definite value for certain types, services and allowable friction losses which increase approximately as the square of the velocity. The free or face area of the heater can be calculated from

$$A = 0.225\ M \div V \qquad (3)$$

where

A = free or face area in sq. ft.
M = pounds of air per hour through the heater
V = air velocity in ft. per min. referred to 70 deg. F.

From a table of guaranteed test data for the heater in question, a heater of the proper surface to meet the velocity, pressure loss and heating requirements can be selected. Friction losses should be kept within the following limits: blast heater 50 per cent of static fan pressure; tempering coil 0.10 to 0.20 in. of water; reheater 0.20 to 0.40 in. of water; air washer 40 per cent of fan system; factory work 0.8 to 1 in. of water.

Steam requirements of the heaters can be calculated as in Eq. 4 of the preceding article and fan power can be calculated from the quantity of air handled and pressure loss as shown in a later article.

Hot-Water Heating for Buildings

ESSENTIAL FEATURES OF A HOT-WATER SYSTEM AND CALCULATION OF REQUIREMENTS

FOR FACTORY buildings or institutions, the essential features of a hot-water heating system include the building equipment of hot-water radiators, piping and control valves; distributing mains and tunnels or

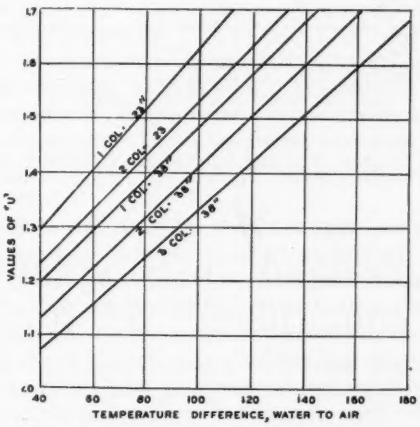


FIG. 1. VALUES SUGGESTED BY THE A. S. H. & V. E. FOR THE HEAT DISSIPATION COEFFICIENTS U OF VARIOUS TYPES OF HOT WATER RADIATORS

conduits, with all necessary expansion provisions, valves, chokes, service connections and insulation; water heating equipment, which may be boilers, heaters taking live, exhaust or bled steam, expansion tank and, usually, a circulating pump.

In planning a hot-water heating system, the first requirement is to determine the maximum demand in British thermal units per hour and when this is known the radiators should be so distributed in the various rooms heated as to permit the radiation of sufficient heat to raise the temperature to that desired under the most severe conditions. Heating requirements have been discussed in connection with steam heating and as the problem for hot-water heating is precisely similar the reader is referred to that discussion.

To determine the amount of radiating surface necessary in a given location, it is necessary to consider the type of radiator selected and the temperature difference,

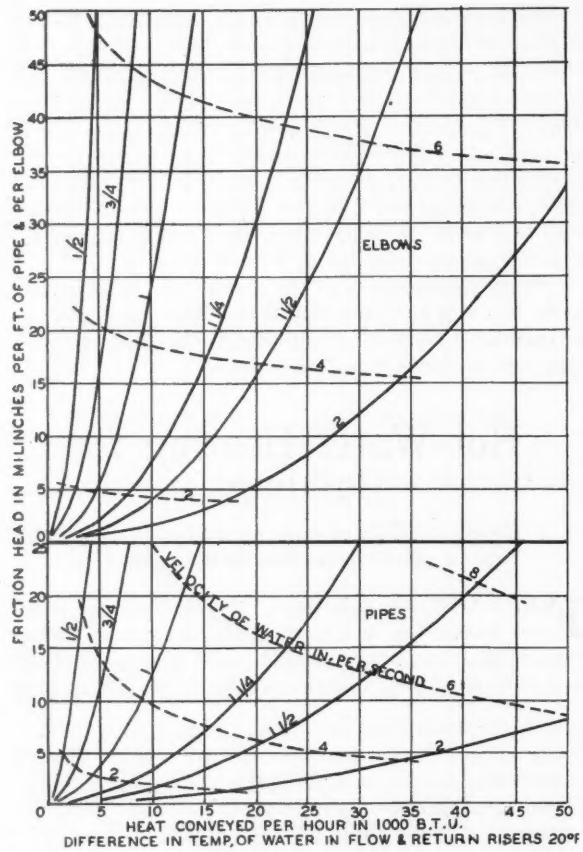

FRICTION HEAD IN MILINCHES PER FT. OF PIPE & PER ELBOW
ELBOWS
PIPES
VELOCITY OF WATER IN FEET PER SECOND
HEAT CONVEYED PER HOUR IN 1000 B.T.U.
DIFFERENCE IN TEMP. OF WATER IN FLOW & RETURN RISERS 20°F

FIG. 2. FRICTION HEAD IN SMALL PIPES AND ELBOWS FOR A 20-DEG. TEMPERATURE DIFFERENCE OF THE WATER IN THE FLOW AND RETURN LINES

water to air. Figure 1 gives the coefficient of heat transmission for various types of radiators and temperature differences. This coefficient is the amount of heat in B.t.u. transmitted to the air per square foot of surface per degree difference in temperature between the water on the inside and the air on the outside of the radiator. Thus, knowing the coefficient of heat radiation for the particular type of radiator used, multiplying it by the temperature difference and dividing the product into the maximum heat requirement in B.t.u. per hour will give the square feet of radiator surface required.

Water Temperatures

In hot-water heating, it is customary to select 180 deg. as the maximum temperature of the water leaving the heater. Likewise common practice indicates that the drop in temperature through the radiator averages about 20 deg., thus making the average radiator temperature 170 deg. Again, custom decrees an average room temperature of 70 deg., so that under average conditions the temperature difference is about 100 deg. Some engineers, however, select 220 deg. as the maximum temperature on the basis that the minimum outside temperature for which the heating system is designed and for which the heat losses are calculated occurs only a few times in any one year and perhaps never in some years. Thus by raising the temperature of the water, greater temperature differences, water to air and entering to leaving water, can be maintained which may reduce materially the size of the radiators and initial cost of the system.

In order to use a maximum temperature of 220 deg., the system must be worked at a pressure sufficient to prevent steam formation in any part of the system; this is about 3 lb. gage. Such a low pressure as this can easily be arranged for in closed systems and in open systems it is only necessary to place the expansion tank at a sufficient altitude above the highest point in the heating system to secure the desired pressure. Thus for each pound pressure above atmospheric it is desired to carry the system the expansion tank must be elevated about 2.3 ft. above the highest radiator.

When the maximum temperature has been determined for the minimum outside temperature, the required water temperature for any outside temperature may be calculated and tabulated or plotted as a curve for the individual system. This calculation, however, should be checked against actual operating conditions and corrections made for wind direction and velocity which have been found to give satisfactory results.

To determine the amount of water required per hour, it is necessary to know the amount of heat required and the drop in temperature through the radiators. With this information, the pounds of water may be found by dividing the heat required in B.t.u. per hour by the drop in water temperature. In factory or institutional heating, desired temperatures may vary in different departments and to give satisfactory service means should

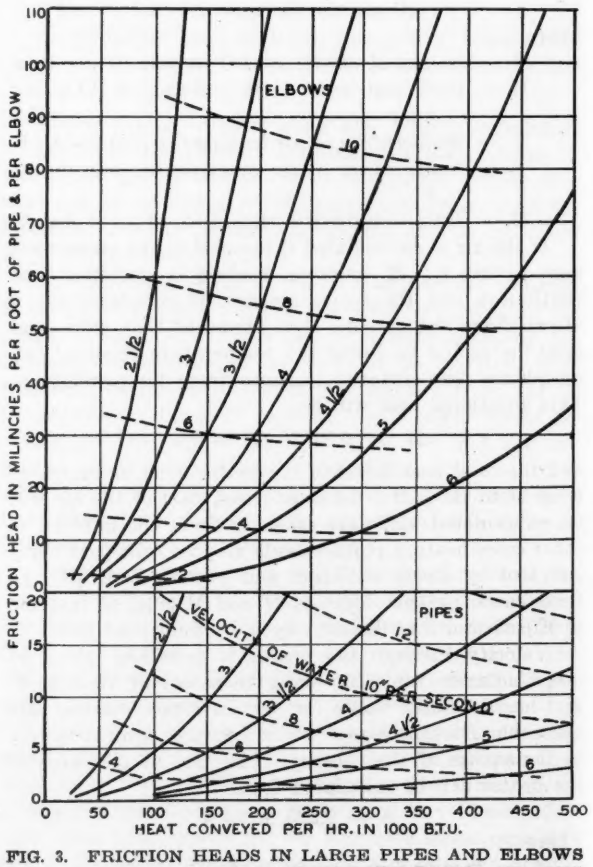

FRICTION HEAD IN MILINCHES PER FOOT OF PIPE & PER ELBOW
ELBOWS
PIPES
VELOCITY OF WATER 10" PER SECOND
HEAT CONVEYED PER HR. IN 1000 B.T.U.

FIG. 3. FRICTION HEADS IN LARGE PIPES AND ELBOWS FOR A 20-DEG. TEMPERATURE DIFFERENCE OF THE WATER IN THE FLOW AND RETURN LINES

be provided for regulating the amount of heat, that is, the volume of water, to each department separately.

Water circulation may be maintained either by the difference in head pressure in the hot supply risers and the cold return pipes or by forcing circulation by means of circulating pumps; the latter is the most commonly employed in large heating systems.

For natural circulation, the most satisfactory location of the water heater is at the lowest elevation in the heating system with the hot water leaving the top of the heater passing to the radiators and the cold water returning to the bottom of the heater. Hence, circulation will increase with the elevation of the water columns and with the difference in temperature. Several arrangements for piping radiators have been devised with the object of maintaining the pressure head in the circuit of that radiator when the system is operating at a uniform rate and when each radiator is producing its correct quantity of heat.

Selection of Proper Pipe Size

Determination of pipe sizes can be made only after the arrangement of circuits has been selected. In making calculations, it is customary to assume the pipe sizes and then calculate the pressure head and the friction head for every circuit. The correct pipe size is that which causes the two heads to be practically equal. When a material difference in calculated results is secured, a change is made in the pipe size, or a portion of the piping, and friction head calculations are made again. This process is repeated until the desired friction head is secured.

Pressure head is calculated by first finding the difference in weight per cubic foot between the water in the flow risers and that in the return risers, this difference in pounds is multiplied by the vertical distance in feet from the center of the heater to the average elevation of the distributing main, then divide this product by the average weight per cubic foot of the flow and return water and the result will be the pressure head in feet which can be converted to inches of water pressure by multiplying by 12. These calculations are usually carried out for the maximum heat demands on the system.

Friction head of the system is made up of the sum of all friction heads including piping, elbows, bends, tees, valves, radiators and heater.

Number of elbows equivalent to fittings usually employed are as follows:

1 90-deg. elbow	1.0
1 45-deg. elbow	0.7
1 90-deg. long turn elbow	0.5
1 Open return bend	1.00
1 Tee	2.2
1 Open gate valve	0.5
1 Open globe valve	12.00
1 Angle radiator valve	2.00
1 Radiator	3.00
1 Heater	3.00

These figures together with Figs. 2 and 3 will give data sufficient for making the calculations. In calculating friction heads for different systems of piping, the principle for all is that the friction head in every radiator circuit must be equal to the pressure head available for that circuit.

In forced circulation systems, the pressure heads are produced largely, or entirely by a pump. This is usually placed in the return line and discharges directly to the heater although it may be at any point in the main. The pump will increase the circulation considerably above that maintained by natural circulation, consequently more water can be circulated through the system, thereby reducing the temperature drop through the system and as a result smaller radiators and pipes may be used, thereby further increasing the velocity of the water and the power necessary to circulate it.

It is more economical to use gravity circulation except when the increase in cost produced by installing the pump and by operating, maintaining and replacing it, when that becomes necessary is less than the saving effected by using the smaller pipes and smaller radiators, made possible by the use of the pump.

Hot water used in large heating systems is nearly always heated by steam exhausted from engines or turbines supplemented at times by bled or live steam. The heater may be a surface condenser with the circulating water used and cooled in the house heating system, or it may be a heater specially designed for water heating. Heaters of the latter type usually consist of hot-water tanks in which are placed submerged steam coils or tubes of copper, brass or iron. With such arrangements heat transmission values range in practice, between 300 and 400 B.t.u. per sq. ft. per hr. per deg. difference between the temperature of the steam and the average water where circulation is maintained by a pump. Because of variation in coefficient of heat transmission of various types of heaters, specification should be drawn up on the quantity and temperature of water required rather than the square feet of heating surface contained in the heater.

Power and Heat Requirements for Air Conditioning

Pumps, Fans, Filters and Heaters Require Plant Services in Laundering Air

OF RECENT years, the need for air of specific humidity as well as temperature has been growing, not only in the heating of public buildings but in many industrial processes. Air free of dust and suspended particles is also demanded for ventilating systems and cooling electrical machinery such as generators and transformers. To meet these demands systems of air filtering, washing and humidifying have been developed the whole process being carried out in one unit called an air conditioner of which Fig. 1 is a typical diagram.

Air is drawn from outside the building through a duct under damper control. It first mixes with a controlled amount of recirculated air then passes at a velocity between 500 and 600 ft. per min. through a spray of water, the temperature of which is controlled to suit conditions desired. From the spray, the air passes through the eliminator, the function of which is to remove entrained water and dust particles that have not been caught by the water spray. The next step in the process is to raise the temperature to that desired by passing air over heating coils, then the fan that

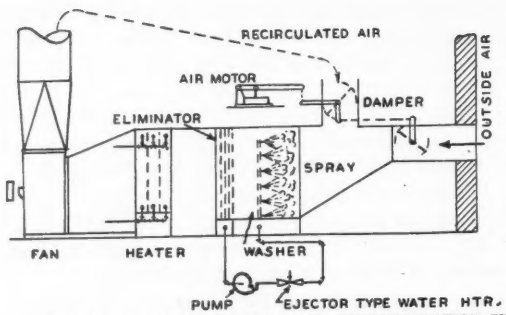


FIG. 1. DIAGRAM OF TYPICAL AIR CONDITIONING UNIT

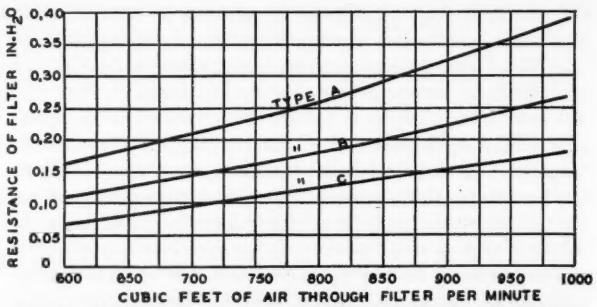


FIG. 2. RESISTANCE TO AIR-FLOW OF THREE TYPICAL AIR FILTERS

furnishes the motive power for moving the air delivering it to the ventilating system.

As a result of passing through such a unit, the air is cleaned of dust particles, its humidity is brought to the proper degree of saturation, the temperature is brought to the desired point and the pressure given to the air on leaving the unit is sufficient to deliver it in needed quantities to the desired points.

What the power engineer in charge of such a unit needs to know is the quantity of water used in spraying and washing, power used in circulating the water, heat required to maintain spray water at proper temperature, heat required to temper the air and power required by the fan.

Spray water at a temperature below the dew point of the incoming air turns the air washer into a dehumidifier, i.e., it actually takes moisture out of the air which may be the desired result in sultry weather and when the unit acts as a cooler. To put moisture into the air, the spray water temperature must be above the dew point of the incoming air. Thus the humidity of the air leaving the washer can be controlled by controlling the spray water temperature. By raising the dry bulb temperature of the air after it leaves the washer, its relative humidity may also be controlled. In climates where severely cold weather occurs, the units are provided with tempering coils at the entrance to prevent the spray water from freezing.

Water Used to Humidify

The amount of water actually absorbed by the air in passing through the humidifier depends upon the relative humidity and temperature of the air entering and leaving the washing element as well as the amount of air. This can be calculated by reference to the psychrometric chart given in handbooks on heating. It is not likely that it will ever exceed 1 lb. of water per 1000 cu. ft. of air conditioned.

Heating engineers have defined the humidifying efficiency of an air washer as the difference between 1 and the ratio of the final wet-bulb depression to the initial wet-bulb depression. A good air washer will have a humidifying efficiency of 70 per cent, while the humidifying type of air washer will have an efficiency ranging from 95 to 98 per cent.

HEAT REQUIRED PER 1000 CU. FT. OF AIR FROM VARIOUS OUTSIDE WET-BULB TEMPERATURES TO VARIOUS RELATIVE HUMIDITIES AT 70 DEG. F. DRY-BULB TEMPERATURE

Wet-Bulb Temperature of Entering Air, Deg. F.	Relative Humidity, Per Cent at 70 deg F. (And Dew Point, Deg. F.)					
	30% (37.25) deg. D.P.	40% (44.5)	50% (50.5)	60% (55.3)	70% (59.6)	80% (63.5)
-10	1194	1452	1653	1860	2044	2245
0	984	1246	1447	1663	1840	2039
10	750	1025	1228	1445	1621	1822
20	510	779	983	1200	1377	1581
30	300	496	700	920	1097	1300
40	...	178	384	603	783	987
50	...	...	...	220	394	619
60	...	...	...	...	...	181

Power required for operating an air conditioning unit is used in circulating the water and driving the fan. It can usually be assumed that to condition 1000 cu. ft. of air per minute 7.5 gal. of water will be circulated at a head of 46 ft. and with a pump having an efficiency of 40 per cent the horsepower of the pump would be 0.218.

Power for driving the fan depends upon the resistance of the ducts, heater and washer and the fan efficiency. If it can be assumed that the total resistance is 1 in. of water and the fan efficiency is 50 per cent, the fan brake horsepower will be

$$\frac{5.2 \times 1 \times 1000}{33{,}000 \times 0.50} = 0.315$$

For 1000 cu. ft. of air handled per minute the power required will be $0.218 + 0.315 = 0.533$ hp. The electrical horsepower input to the motors will be approximately 1½ times this amount when the efficiency of the motors is taken into consideration.

Heat required for conditioning air is most easily obtained by use of the table, which gives the heat required in B.t.u. to heat 1000 cu. ft. of air from various outside wet-bulb temperatures to various relative humidities at 70 deg. F. dry-bulb temperature. The amount of heat for humidifying alone is found by deducting, from the values given, the heat required to raise the temperature of 1000 cu. ft. of air between the temperature limits specified by means of the formula:

$$H = 1000 \times \frac{t_2 - t_1}{55.5}$$

where H = heat required per 1000 cu. ft. in Bt.u.
$t_2 - t_1$ = temperature elevation in degrees F.

Air Filters

In many industrial applications, air filters are used in preference to air washers for removing fine particles of dust. Air filters do not use water nor do they change the temperature or relative humidity of the air passing through them. The features required of all types of air filters are: effectiveness in removing dirt, low resistance to the flow of air, large capacity for holding dust, and ease of cleaning and handling.

Air filters may be either of the dry type which consists of a fine mesh cloth, felt or paper screen through

which the air is filtered, or of the viscous type which depends, for its cleaning action, on the impingement of the dirt particles on a metal surface coated with a viscous fluid.

Efficiency of dust removal by filters is expressed by the following formula:

$$E = 1 - \frac{\text{Weight any sample leaving}}{\text{Weight any sample entering}}$$

Figure 2 shows the resistance three typical air filters offer to the passage of air at various capacities and from this it will be noted that the resistance varies widely with the type of filter so that power consumption calculations must be based on manufacturers' guarantees or on operating results if the unit has been installed.

The static head increases with the accumulation of dust so that frequent cleaning is desirable.

Steam for Process Work in Industrial Plants

Amounts, Pressures and Temperatures of Steam Used in Textile, Paper, Food, Laundry, Hotel and Other Industries

AMOUNT, PRESSURE and temperature of steam used in industrial processes vary widely, of course, with the processes themselves. Even in similar processes carried on by different manufacturers in the same industry there will be some variation due to local conditions and slight modifications of processes. Some general figures, however, are available on a few of the major steam using industries. This article will present them briefly and will also give some typical figures for particular plants.

In the beet sugar industry, for example, where the process is mostly one of evaporation, the practice is to use steam for process work of the lowest pressure available. Table I shows those usually employed; third and fourth vapors under vacuum are ordinarily used for heating raw diffusion juice which has a temperature of 30 to 45 deg. C. Second vapors under pressure are in general used throughout the plant for heating purposes and first vapors sometimes when the heater is small and higher temperature is needed. Exhaust at 15 lb. is always used on first body evaporators and vacuum pans.

TABLE I. STEAMS AND VAPORS USED IN SUGAR PLANT AND THEIR PROPERTIES WITH QUINTUPLE EVAPORATOR

	Gage press. lb. sq. in.	Temp. Deg. F.	Heat of liquid	Heat of vaporization	Total heat in steam
Live steam	135	358.5	330.2	863.2	1193.4
Boiling main	75	320.3	290.5	893.9	1184.4
High exhaust	50	298.0	265.7	911.0	1178.5
Standard exhaust	15	250.3	218.8	945.1	1163.9
First vapors	9	237.0	206.0	953.5	1159.5
Second vapors	4	225.2	193.4	961.8	1155.2
Third vapors	2" vac.	209.0	176.0	971.0	1149.0
Fourth vapors	12" vac.	188.3	156.2	985.0	1141.1

General practice on white sugar vacuum pans is to use live steam reduced to 80 lb. Sometimes engine exhaust at 50 lb. is used or live steam at 145 lb. where operation at high capacity is required. Steam distribution is as shown in Fig. 1.

In paper mills, the cooking of pulp may require from 6000 to 10,000 lb. of steam per ton of product at 60 to 125 lb. pressure. Bleaching requires roughly 2000 lb. steam per ton, while drying of paper in the machines may require 5000 to 10,000 lb. per ton, using low-pressure or exhaust steam.

In the food products industry, a certain cereal factory uses steam for evaporators, dryers and cookers, for heating water, materials and buildings. Process steam is supplied at 125 lb. pressure. By locating dryers and evaporators on the third floor, vacuum pumps are eliminated and air ejectors maintain the vacuum, the exhaust steam from the ejectors supplying steam to evaporators and dryers.

Steam in Hotels

The hotel industry uses large quantities of steam for various purposes. In an 1100-room hotel, for example, in one month 1,102,800 lb. steam went to the kitchen, 1,488,000 lb. to the laundry and so on. Low-pressure steam, 2 to 5 lb. gage, is required for building heating and for the tremendous quantities of hot water.

In the chemical industry, live steam at 100 to 300 lb. per sq. in. and exhaust steam at 1 to 60 lb. per sq. in. are used for distillation, evaporating, concentrating, rectifying drying, sterilizing, heating and washing. In one plant, steam is generated at 130 lb. and used at this pressure in all stills, requiring jacket temperatures of 300 deg. F. or over. On processes requiring tempera-

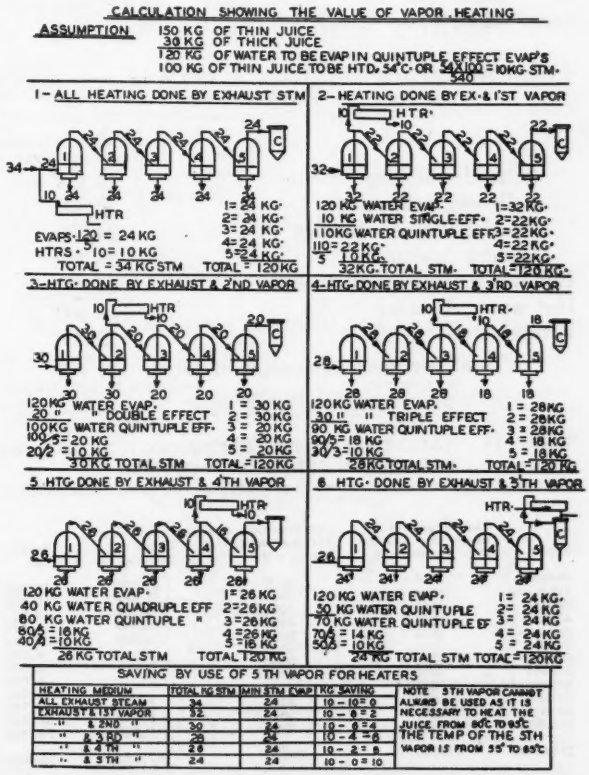

CALCULATION SHOWING THE VALUE OF VAPOR HEATING
ASSUMPTION
150 KG OF THIN JUICE
30 KG OF THICK JUICE
120 KG OF WATER TO BE EVAP IN QUINTUPLE EFFECT EVAP'S
100 KG OF THIN JUICE TO BE HTD. 54°C. OR 54X100 = 10KG STM.
540
1- ALL HEATING DONE BY EXHAUST STM
2- HEATING DONE BY EX. & 1ST VAPOR
3- HTG. DONE BY EXHAUST & 2ND VAPOR
4- HTG. DONE BY EXHAUST & 3RD VAPOR
5 HTG. DONE BY EXHAUST & 4TH VAPOR
6 HTG. DONE BY EXHAUST & 5TH VAPOR
SAVING BY USE OF 5 TH VAPOR FOR HEATERS
HEATING MEDIUM
TOTAL KG STM
MIN STM EVAP
KG SAVING
NOTE
ALL EXHAUST STEAM
EXHAUST & 1ST VAPOR
" & 2ND "
" & 3 RD "
" & 4 TH "
" & 5 TH "
5TH VAPOR CANNOT ALWAYS BE USED AS IT IS NECESSARY TO HEAT THE JUICE FROM 60°C TO 95°C
THE TEMP OF THE 5TH VAPOR IS FROM 55° TO 65°C

FIG. 1. STEAM DISTRIBUTION IN BEET SUGAR FACTORY

TABLE II. TYPICAL MONTHLY REPORT OF AN 1100-ROOM HOTEL

Current Purchased, kw.hr.	254,000
Sold to Tenants, kw.hr.	8,401
To Elevators, kw.hr.	19,516
Passenger Elevator, miles	4,414
Freight Elevator, miles	3,017
Kw.hr. per Car Miles	2.6
Total coal burned, lb.	917,900
Total coal purchased, lb.	1,102,800
Total steam to kitchen, lb.	1,488,190
Total steam to laundry, lb.	1,061,700
Total water evaporation, lb.	8,663,000
Average evap. per lb. of coal	9.5
Total consumption of water, gal	13,967,000
Kitchen water, gal.	3,740,000
House water, gal.	7,977,400
Laundry water, gal.	2,249,600
Auxiliary kitchen gas, cu.ft.	235,600
Main kitchen, cu.ft.	228,300
Guest cafeteria, cu.ft.	65,100
Help's cafeteria, cu.ft.	20,300
Bake shop, cu.ft	142,300
Cakes of ice	596

tures of over 212 deg. but less than 300 deg., 15 lb. exhaust steam is used.

Laundries need steam at about 100 lb. pressure for ironers, presses, stocking forms and the like. For heating water to about 180 deg., exhaust steam at 3 to 5 lb. gage pressure is often employed.

Silk Mills

In silk mills, steam is used for direct heating of soapy water in degumming and for heating of solutions in dye vats. Low-pressure steam can be used in the early parts of the processes but for dyeing, 60 lb. or more pressure is needed. In one mill, the unit costs per 1000 yd. of piece goods include an item of 3917.2 lb. of steam per 1000 yd. of goods. In another mill, about 4200 lb. of steam are required for 1000 yd. of

TABLE III. STEAM USES FOR A YEAR IN A 45-STORY HOTEL

	Thousands of Pounds of Steam per Year
A. I. U. building heating	11,110
Ballroom heating	2,800
Deshler-Wallick heating	24,000
Deshler heating	25,200
Hot water, Deshler-Wallick	18,000
Hot water, Deshler	18,000
Kitchens, etc.	12,000
Total per year, thousands of lb.	111,180

TABLE IV. VARIATION OF THE STEAM LOAD BY MONTHS FOR HOTEL SHOWN IN TABLE III

Month	High Pressure Steam for Laundry, etc. Month - M.	Low Pressure Steam for hot water Month - M.	Low Pressure Steam for heating Mo.-M.	Total M.
January	1000	3000	14,500	18,500
February	1000	3000	11,400	15,400
March	1000	3000	9,500	13,500
April	1000	3000	5,695	9,695
May	1000	3000	1,280	5,280
June	1000	3000		4,000
July	1000	3000		4,000
August	1000	3000		4,000
September	1000	3000		4,000
October	1000	3000	3,780	7,780
November	1000	3000	8,240	12,240
December	1000	3000	8,785	12,785
Total M.	12000	36000	63,180	111,180

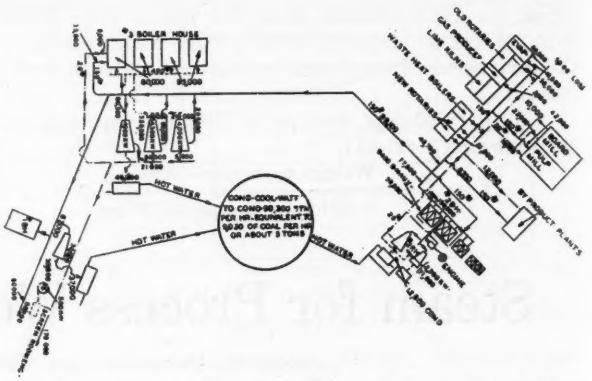


FIG. 2. STEAM AND WATER DISTRIBUTION IN A LARGE PAPER MILL

product. Still other analyses of silk mills show the following:

Boil off ..... 440 lb. steam per 1000 yd.
Dyeing .....4700 lb. steam per 1000 yd.
Finishing ..... 600 lb. steam per 1000 yd.

In rayon mills, a considerable amount of the heat supplied is in the form of hot water, which will be discussed in the following article.

Data on steam and hot water heating for another large 45-story hotel building are shown in the Tables III and IV, the total steam consumption for the year being about 111,000,000 lb., a considerable portion of which is exhaust steam.

In a large pulp and board mill, exhaust steam from turbines at 20 to 25 lb. pressure is used in dryers and for other processes. From the turbines, 80-lb. steam is bled for the processes, supplemented by live steam through desuperheater and reducing valves.

Paper Mills Use Large Amounts of Steam

Another paper mill employs an accumulator for storing exhaust steam from its generating units, to balance up its steam and electric load conditions. Paper machine dryers take exhaust steam at 23 lb. supple-

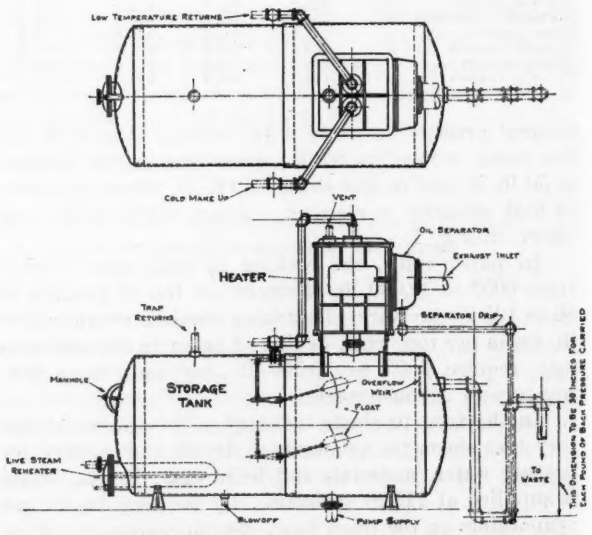


FIG. 3. OPEN STORAGE HEATER MOUNTED ON STORAGE TANK

mented by live steam reduced to 45 lb. for calendar rolls. For the mill, steam consumption data are as follows, for summer conditions:

Production — Average—160 t. per day
Peak—207 t. per day
Steam—Average— 80,000 lb. an hour
Peak—110,000 lb. an hour

At a large plant manufacturing radio equipment, evaporators are used not only to supply pure boiler feed makeup water but also to supply heating steam to the system at 15 lb. gage during the winter and to heat

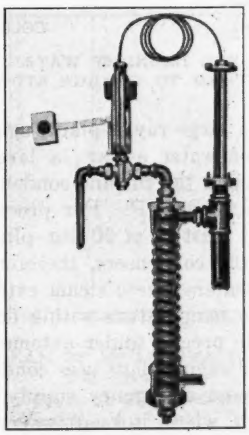


FIG. 4. FILM TYPE HEATER WITH AUTOMATIC CONTROL

boiler feedwater in summer. This plant has a process steam load of approximately 30,000 lb. an hour, supplied at 45 lb. pressure partly from the exhaust of a steam turbine and partly through a reducing valve from the main steam header. Except under extreme conditions, steam goes to the evaporators at 45 lb. gage. The heating load for the buildings will average about 90,000 lb. an hour.

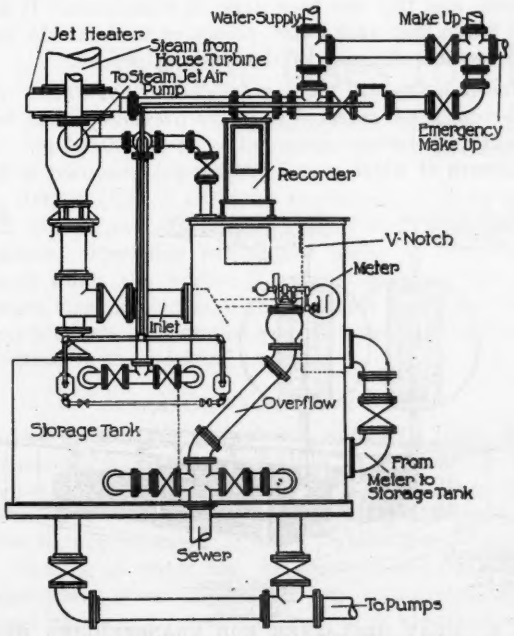


FIG. 5. ONE METHOD OF USING A JET HEATER

Water Heating an Important Use

One of the principal uses for steam in all industries is for the heating of water to various temperatures for use in the processes. This is done by storage water heaters of various types, heat exchangers using waste water that contains reclaimable heat, direct contact jet heaters, and, of course, by direct contact of steam in the process itself.

For laundries, the method indicated below has often been widely applied. A water heating tank is provided, having small storage capacity, to which exhaust steam is admitted if it is available, together with live steam under thermostatic control. Steam consumption of the heater is continuous, the fluctuations being taken up by the storage tank. A pump between the two heaters maintains circulation and operation of the hot water heater stops only when the storage tank is filled with hot water down to the bottom, in which case a thermostat stops the pump and cuts off the steam.

Another type of hot water storage heater is shown in Fig. 3. This is of the open type, designed to deaerate the water and heat it with exhaust steam, supplemented by live steam if necessary. Storage heaters of the closed or surface type are also used for heating process water.

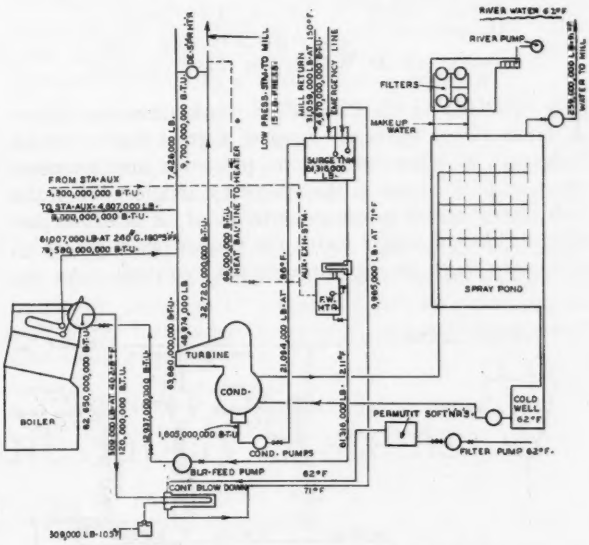


FIG. 6. HEAT FLOW DIAGRAM IN A RAYON PLANT

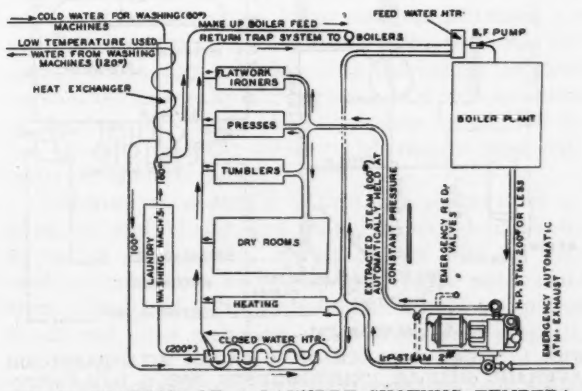


FIG. 7. DIAGRAM OF A LAUNDRY SHOWING TEMPERATURES AND PRESSURES

In these, the steam passes through bundles of tubes in the heater, the water being in the shell surrounding the tube bundle.

Jet Heaters

Jet heaters are suited to large capacities, of 200,000 lb. an hour or more of water. They are designed to heat the water almost to steam temperature; they can operate under back-pressure or vacuum and change automatically from one to the other according to variations in flow of water or steam. Where deaeration, operation at fractional load for long periods are necessary or where ample head is not available, they are not so often used but these conditions seldom obtain in heating process water and they are often used for this purpose.

Direct contact heating by introducing steam directly into vats or agitators is often practiced in industrial processes. Sometimes various types of diffusers are used for this purpose; often a perforated pipe or a special device furnished by the maker of the process equipment.

Hot Water for Industrial Processes

Data from Typical Industrial Plants Showing Amounts and Temperatures of Water for Various Uses

IN INDUSTRIAL PROCESS work, immense quantities of hot water are needed, a great deal of which is heated by steam at various pressures and temperatures, as pointed out in the preceding article. When the industry operates its own power plant, it is often possible to use condenser water for process work where an extremely high temperature is not required. An example of this is a large rayon plant, using two to three million gallons of water a day; a large part of this water passes through the turbine condensers where it is heated almost to 90 deg. F. For process work in the spuming rooms it must be at 90 deg. plus or minus one. After it leaves the condensers, therefore, it is passed through closed heaters where steam extracted from the turbine keeps the temperature within one degree of 90 deg. F., the whole process under automatic temperature control. Another rayon plant uses condenser water for spuming, storing an emergency supply in large tanks in its boiler room, where it keeps warm and ready for emergency use. In an emergency, it can be drawn from the tanks to the extraction heaters for heating to 90 deg.

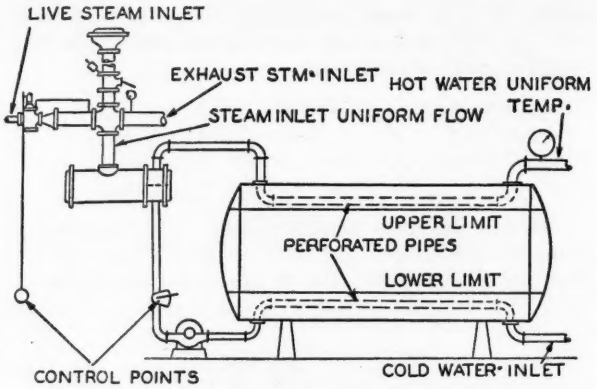


FIG. 2. HEATER FOR LAUNDRY WATER USES EXHAUST AND LIVE STEAM TO CHARGE STORAGE TANK

Hot Water for Paper Mills

In paper mills large quantities of water are used, not all of which is heated, however. For washing pulp after cooking, warm water is often used, requiring a heat equivalent of 6000 to 8000 lb. of steam per ton of pulp washed. It has been suggested that this heat can be supplied by the heat of the stock discharged from the digester and this has been done in some cases. It has been found that wash water, preheated to about 115 deg. increases the efficiency of the washing process.

Large hotels will use a great deal of hot water. An 1100-room hotel, referred to in the previous article, had a monthly hot-water consumption of 13,000,000 gal. for one month of which over 3,000,000 gal. was used in the

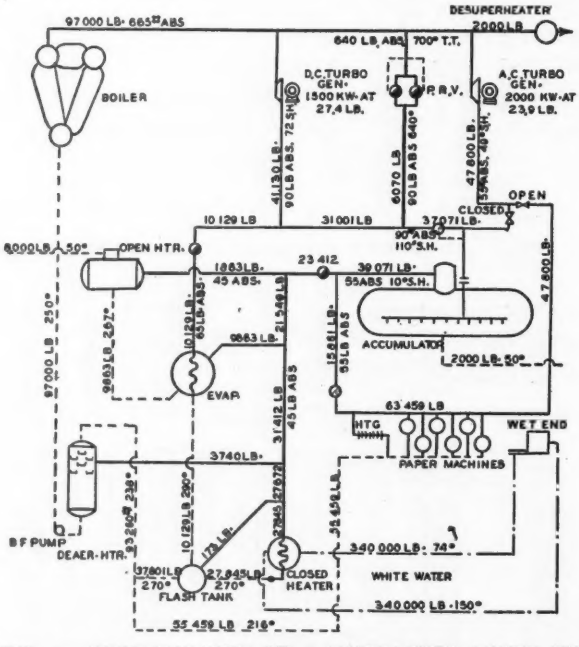


FIG. 1. HEAT BALANCE OF A PAPER MILL BASED ON AVERAGE HOURLY REQUIREMENTS FOR A DAILY OUTPUT OF 225 T. THIS ILLUSTRATES A MODERN USE OF THE ACCUMULATOR

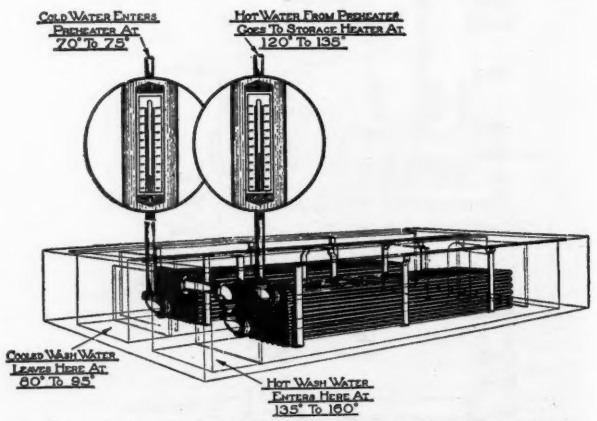

COLD WATER ENTERS PREHEATER AT 70° TO 75°
HOT WATER FROM PREHEATER GOES TO STORAGE HEATER AT 120° TO 135°
COOLED WASH WATER LEAVES HERE AT 60° TO 85°
HOT WASH WATER ENTERS HERE AT 135° TO 160°

FIG. 3. HEAT RECLAIMER FOR TRANSFERRING HEAT FROM DIRTY WASTE LIQUIDS TO INCOMING WATER

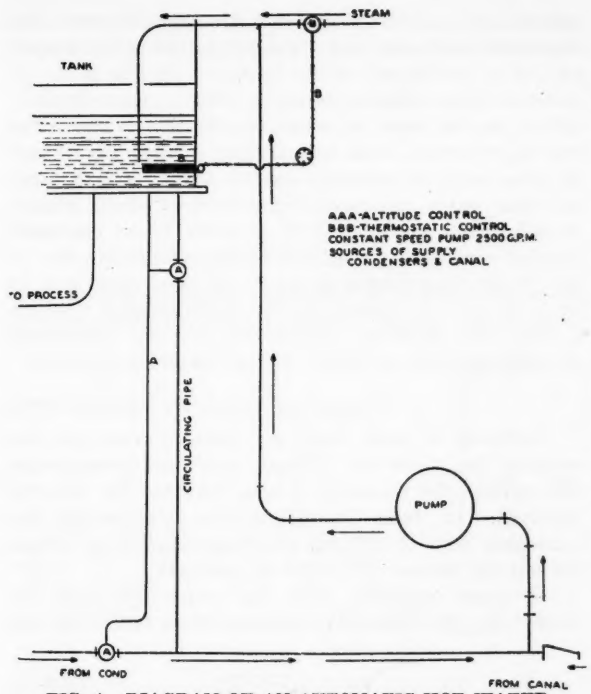


FIG. 4. DIAGRAM OF AN AUTOMATIC HOT WATER GENERATOR

As the head in the tank increases, the circulating valve opens and the condenser valve closes. Canal water flows only when condensers shut down.

kitchen, 8,000,000 for house water and over 2,000,000 for the laundry. The house hot-water system usually supplies water at about 140 deg., while kitchen and laundry water is about 180 deg. Regulation is usually effected by thermostatic controls on the water heaters.

In laundries, on the average, about 70 or 80 per cent of the total heat used is employed in generating hot water, which goes to the laundry machines usually at about 180 deg.

Silk mills usually carry on their dyeing operations in vats, the water and dyes being cold at the beginning of the process. By introducing steam directly into the vats, boiling temperatures are obtained which help to set the colors. Some of these mills will use about 24,000 cu. ft. of water per 1000 yd. of products but not all of this is heated in every case.

Water for Textile Mills

In modern textile mills, the dye house will consume approximately 40 per cent of the total fuel heat, therefore it makes a great deal of difference whether the kettles are boiling violently or mildly, and that 40 per cent may be increased to 50 if improper methods are employed. Automatic control methods have progressed so rapidly that it is now possible to determine the time limit on bringing to a boil, holding at boiling and closing. For instance a certain dye may require 45 min. of preparation before the goods can be put in, then the same length of time for gentle boiling. The control equipment can be set so that the boiling point will be held at 210 or 211 or 212 or 213 deg. or wherever desired. When chemicals are added to water, its boiling point may change. In addition, the altitude affects the boiling point appreciably and these factors must all be taken into account when controlling the boiling of water with steam. Figure 4 shows an automatic hot-water generator devised by one textile mill engineer.

Use of accumulators to store heat in water has been referred to above but in most cases this is done so that steam and not hot water can be produced by the accumulator. Various types of storage heaters for hot water are available, as referred to in the previous article.

Large quantities of water are used in air conditioning equipment installed for improving the quality of industrial products by providing proper humidity, as well as for increasing the comfort and healthfulness of the working spaces.

Water Uses for Plant Supply Systems

Sources of Supply and Systems of Distribution for Wash Rooms, Toilets, Drinking Water and Fire Protection

ADEQUATE WASHING facilities in a plant make for better health and increased self-respect of the workers. Provision for shower baths in factories is urged where the worker is exposed to great heat, excessive dust or contact with poisonous materials, where food products are handled and bathing facilities are inadequate in the workers' homes.

Automatic Valves Save Water

For many types of factories, automatic flushing arrangements which are actuated by contact with the seat, are preferred for toilet service. Where there is no regulation by law of the number of closets, a ratio of one toilet fixture for every 15 or 20 persons may be used.

Heating of water may be accomplished by exhaust steam where steam is employed; by heat exchangers in Diesel plants or by means of gas, oil or electric heaters for rapid heating. Electric heaters range in capacity from 60 to 5000 gal. capacity and with a temperature rise of 100 deg. in 3 hr. Prevention of waste is an important matter where large amounts of water are used because of the tendency to allow faucets to run full open. Waste may be reduced by decreasing the pressure on the line or by placing washers with small holes in the faucets. Waste at showers may be avoided by use of chain operated valves which remain open only while the chain is pulled.

Drinking water should be kept at a temperature between 45 and 50 deg. and should be cooled indirectly by ice or refrigerated. Direct contact with ice may cause contamination and generally cools the water more than is healthful. Proper insulation should be applied to all cold pipes including outlet loops, riser supports, and fittings.

Where water is supplied to several buildings differing greatly in size, hence requiring different quantities

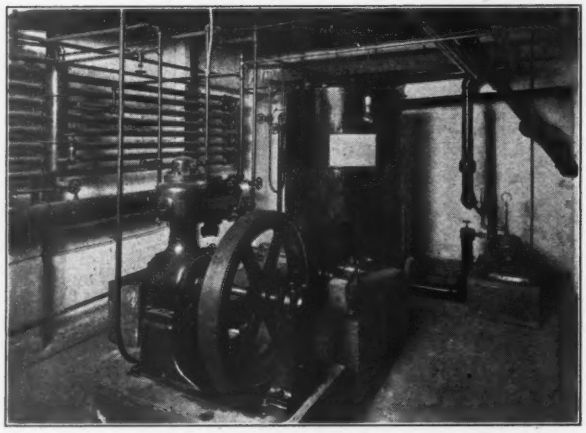


FIG. 1. TYPICAL REFRIGERATING PLANT FOR DRINKING WATER

of water, it is best to lay out the distribution system with a separate loop for each building as shown in Fig. 4. Where water is supplied to high buildings, expansion or surge tanks are needed to even the pressure. Dead ends at fountains are the source of loss of water and advisable to install a sedimention tank between the coagulant treatment and the filter to allow for proper settling of suspended matter as shown in Fig. 5.

Small plant filters, charged with a char product, carbon, special stone or some patented filtering material and no reservoir used, will remove a large percentage of color and, to a certain extent, taste. For a large drinking water system and for food products plants, crystal quartz and char type pressure filters are used. Smaller plants use paper disk filters. Vegetable char is said to be three times as active as bone char and 30 times as active as bone charcoal. Mineral char also has a high and uniform decolorizing power. Hydrogen sulphide gas may be removed from water by aeration.

Water Softening

Softening of hard water for house service prevents clogging the pipes and fittings, aids heat transference and reduces the quantity of soap required for effective washing. In food product plants, eliminating the hardening salts of calcium and magnesium helps retain the natural flavors and color of products.

Principal mediums used for water softening are zeolite and the lime-soda combination in both cold and

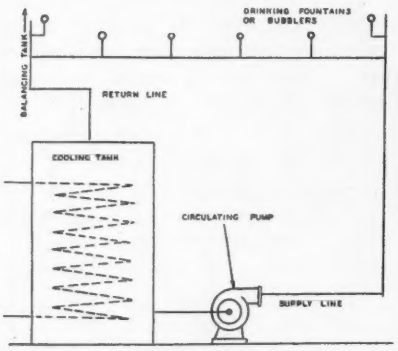


FIG. 2

FIG. 2. COOLED WATER SYSTEM WHERE CITY PRESSURE IS USED

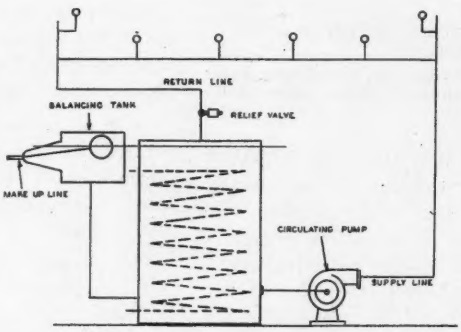


FIG. 3

FIG. 3. COOLING SYSTEM FOR HEAD PUMPED ON SYSTEM

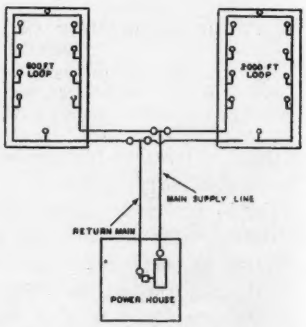


FIG. 4

FIG. 4. PIPING LAYOUT OF A DRINKING WATER DISTRIBUTION SYSTEM

time, as the volume of water contained in the dead end is drawn off before the cool water issues, therefore it is advisable to loop the supply line at the discharge points. In any system where the bubbler supply is taken from a horizontal line, the connection should always be made from the bottom of the pipe since a small quantity of air will travel along the top.

Treatment of Drinking Water

Water treatment for drinking purposes includes chlorination for the destruction of typhoid microbes, coagulation for removing agglomerating suspended particles which cause turbidity and filtration to remove sediment and suspended matter and in some cases odor and coloring matter.

Chlorination is best done by the use of liquid chlorine through a mixing apparatus specially designed for that purpose, as use of chloride of lime usually results in a pronounced taste in the water. The amount of chlorine used ranges from 1 to 5 parts per million. Coagulation may be accomplished either chemically or electrically; the latter, which is the more recent development, operates automatically. For some waters it is hot processes. For industrial purposes, the cold process is usually used but where the water is fed to a boiler of any kind the hot process is preferred because it is more rapid.

Ultra-violet light treatment has been found destructive to bacteria but not odor and disagreeable taste. It should be used only after turbidity is entirely removed and the water filtered. Ozone treatment of water re-

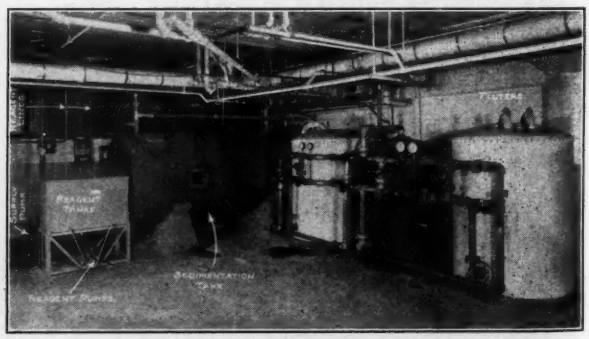


FIG. 5. WATER FILTRATION PLANT WITH CHEMICAL REAGENT PUMP, SEDIMENTATION TANK AND FILTERS

moves both odor and bad taste, also 98 per cent of dissolved organic matter, has no byproducts of reaction and uses no chemicals.

For drinking water, the average consumption by each employe is conservatively estimated, for average conditions, at 0.25 gal. per hr. Steel mills allow 1 qt. per hr. to a person, if cups are used. Ordinarily, if a fountain is used, from 2 to 3 qt. per workman every 8 hr. is sufficient.

Water for Fire Protection

Automatic sprinkler equipment is probably the most effective protection used in plants having considerable

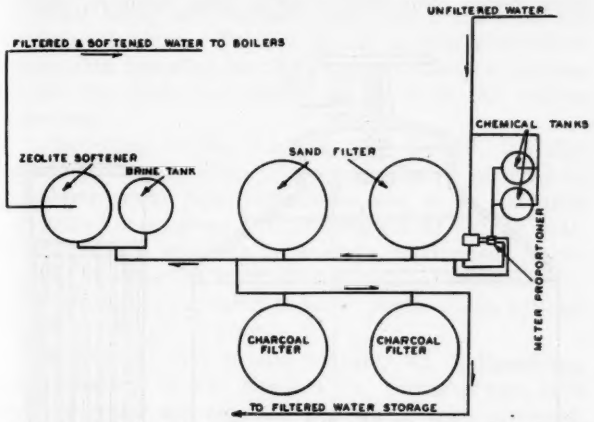


FIG. 6. DIAGRAMMATIC LAYOUT OF WATER TREATING EQUIPMENT FOR A FOOD PRODUCTS PLANT

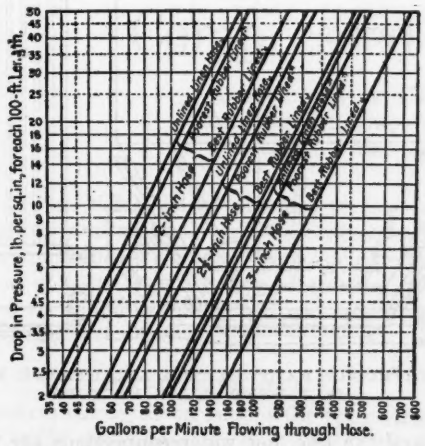


FIG. 7. LOSS OF PRESSURE IN 100 FT. OF FIRE HOSE AT VARIOUS RATES OF FLOW

inflammable material, as, although sprinklers may not extinguish a fire completely they check it at the start.

Two types of sprinkler systems are used; wet-pipe and dry-pipe. In the former, which is the more common and more desirable, water constantly fills the pipes up to the sprinkler heads. The dry-pipe system is used where the building is subject to temperatures below freezing, the sprinkler pipes being filled with air under pressure, no water entering until a sprinkler head opens. Some time, therefore, elapses before the air is exhausted from the pipes and the water flows freely.

Usual sources of water supply are elevated tanks of sufficient capacity to supply the system for ½ to 1 hr. Where high-pressure service is available from city mains, it is substituted for tank supply. Fire pumps, which may be started automatically and which can draw upon an unlimited supply are often installed. Standpipes which can be connected at street level to city fire apparatus are installed in high buildings. Standpipes or risers should be at least 4 in. diameter and, where the building is more than 2 or 3 stories high or where two connections are taken off at any floor, the standpipe should be at least 5 in., preferably 6 in. These standpipes connect to hose reels located on each floor of the building. The National Board of Fire Underwriters has rigid rules for the installation of sprinklers and for

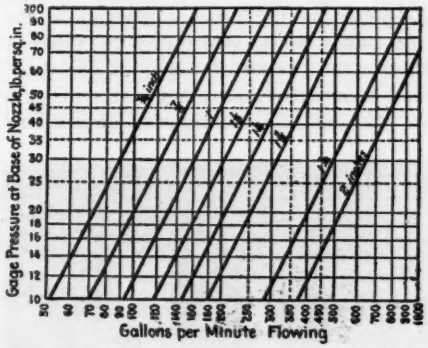


FIG. 8. DISCHARGE FROM FIRE HOSE NOZZLES AT VARIOUS PRESSURES

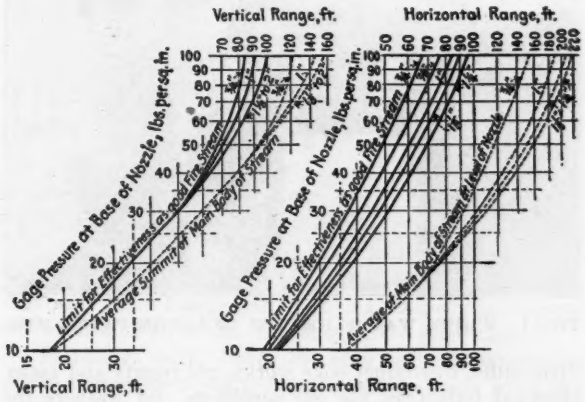

Vertical Range, ft.
Horizontal Range, ft.
Gage Pressure at Base of Nozzle, lbs. per sq. in.
Limit for Effectiveness of Good Fire Stream
Average Summit of Main Body of Stream
Limit for Effectiveness of Good Fire Stream
Average of Main Body of Stream at Limit of Effectiveness

FIG. 9. VERTICAL AND HORIZONTAL RANGES OF FIRE STREAMS

the provision, inspection and use of fire hose. Figures 7, 8 and 9 present data on the use of hose for fire purposes.

The principle of the Joule-Thompson effect is employed in the liquefaction of gases by mechanical means, as in the Linde machine. By a system of progressive compression cooling and throttling, the temperature of the gases is lowered and after a constant temperature has been established, liquid forms almost continuously. Liquefaction of helium, which was first liquefied in 1908, is the nearest approach to absolute zero.

Conservation of energy is known as the first law of thermodynamics. Energy cannot be created or destroyed but all forms of energy are inter-convertible.

Uses of Water in Process Work

WATER IS IMPORTANT FACTOR IN MANY PROCESSES, AS SHOWN BY FIGURES ON USES AND AMOUNTS FOR VARIOUS INDUSTRIES

SUCH A GREAT variety of uses for water exists in industrial processes for washing and heating that it is possible here to indicate only a few of them.

Paper mills, besides using large quantities of water in stock washing, beaters, Fourdriniers, need a large supply also for washing the felts of paper machines. The whole paper-making process depends on the carrying of the paper stock suspended in water until it finally appears as a sheet of paper on the machine.

Railroad terminals employ hot water in large quantities for washing out locomotives and filling them.

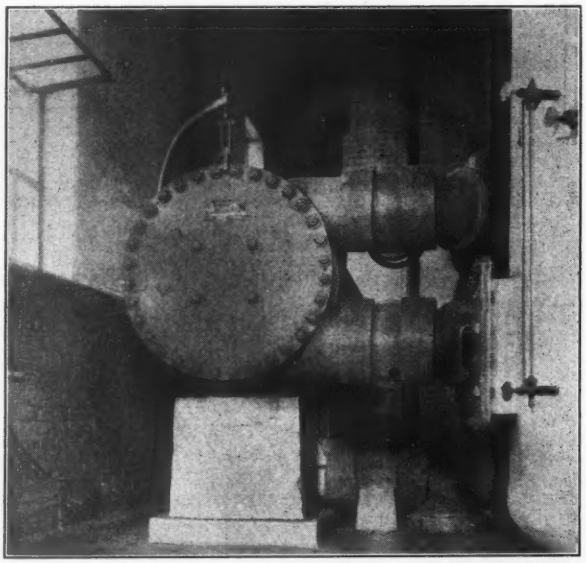


FIG. 1. WHITE WATER HEATER IN LARGE PAPER MILL

Steel mills, byproduct coke works, gas plants and many chemical industries use gas scrubbers and washers for removing solid matter from gas, often recovering products that can be used in other ways. Use of stack sprays and gas washers of various kinds for removing dust and corrosive substances from flue gas of boiler furnaces is increasing in importance.

Use of water in air conditioning equipment is for two purposes; for humidifying or dehumidifying and for washing.

WATER USES IN LAUNDRIES

In laundries hot water is, of course, an essential factor together with soap, in all the processes. The minimum amount of water is about 80 gal. of hot water per 100 lb. of dry clothes. The instantaneous requirements for hot water are made higher than the average demand. For washing fabrics, it is obvious, of course, that exhaust steam containing oil cannot be introduced directly into the water. Washing machines may require from 150 gal. per hour to 600 gal. per hr. depending somewhat on size.

Hot water requirements for kitchens, such as large kitchens of hotels and hospitals may be 20 gal. per hr. for each sink faucet and 40 gal. per hr. per 1000 pieces an hour for the dishwashers. Cold water requirements may be double the hot water requirements. For use in stock kettles, soup kettles, coffee urns, steamers, potato

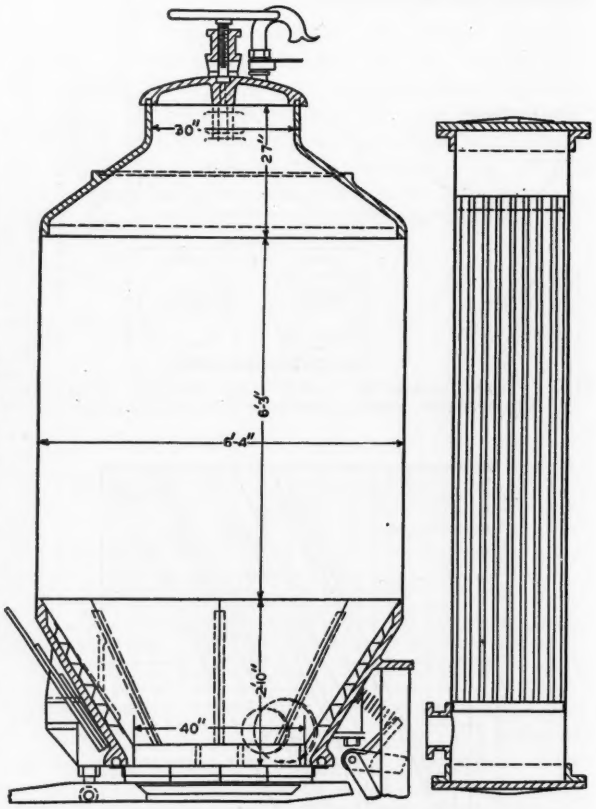


FIG. 2. DIFFUSION BATTERY CELL AND HEATER AS USED IN A BEET SUGAR FACTORY

peelers and the like, hot water connections are usually fitted although they are not always absolutely necessary.

WATER FOR HOSPITALS

Hospitals require a plentiful supply of sterilized and distilled water. Water sterilizers usually consist of twin reservoirs of the same capacity mounted on the same frame. One reservoir is for water kept hot by a steam coil in the reservoir and the other for water somewhat cooled by circulating cold water through a coil in the reservoir. Both reservoirs, of course, have provision for sterilizing their contents.

In the food products industry, beverage industry, sugar industry in refineries, leather plants, by-product coke works to mention only a few, water plays an extremely important part.

Importance of Water to Industry

The following figures may be of interest in showing its importance in some industries.

In the manufacture of pulp and paper, according to data received from The Paper Industry, engineers commonly estimate about 50,000 gal. of water per ton of mechanical pulp, 75,000 gal. per ton of unbleached sulphite pulp, 100,000 gal. per ton of bleached sulphite pulp, 100,000 gal. per ton of soda pulp, 75,000 gal. per ton of sulphate pulp and 30,000 to 40,000 gal. per ton of paper. It is doubtful whether any two mills, even with the same productive capacity, would use exactly the same quantity of water, as so much depends upon the product being manufactured and the practice in the individual plant. Table I shows in convenient form some data compiled by The Paper Industry to demonstrate the great importance of water in the various processes.

According to the Brick & Clay Record, the clay products industry, that is, the manufacture of building products, sewer pipe, refractories and so on, exclusive of pottery, uses about 1,700,000,000 gal. of water a year. This figure is based on an average requirement of one pound of water for every seven pounds of finished ware. This amount is exclusive of boiler plants which will use 3,120,000,000 gal. a year.

For the byproduct coke industry, C. J. Ramsburg, vice-president of The Koppers Co., estimates that 3500 gal. of water are required per ton of coke produced, which would make the total yearly consumption of water 187,164,250,000 gal., or an average of 512,778,767 gal. a day.

The amount of water needed by the domestic rubber manufacturing industry in 1929 was estimated by The Rubber Age to be between 100,000,000 and 120,000,000 gal. per working day. During the same year, the rubber industry consumed about 470,000 long tons of crude rubber. It appears that the manufacturing activity of the industry during 1930 will equal only about 85 per cent of the previous year and it is presumed that the use of water has declined in proportion.

TABLE SHOWING AMOUNT OF WATER USED IN PAPER AND PULP INDUSTRY IN U. S. IN 1927

	Approximate Quantity of Water in Gal. Per Ton	Production of pulp and paper in U. S. 1927	Water Requirements in gallons for a year
Mechanical Pulp	50,000	1,550,000	77,500,000,000
Sulphite Pulp Unbleached	75,000	870,000	65,250,000,000
Sulphite Pulp Bleached	100,000	675,000	67,500,000,000
Soda Pulp	100,000	448,000	44,800,000,000 (Large % bleached used in production of book paper)
Sulphate Pulp	75,000	601,000	45,075,000,000
Paper (all grades)	30,000-40,000 (Wide variation)	9,737,000	292,110,000,000 (Using 30,000 gals. in calculation)
Total gallons of water per year			592,185,000,000

Estimating a 300 day operating year, the pulp and paper mills of the U. S. use approximately 1,973,950,000 gallons of water per day.

Compressed Air Industrial Uses

Applications of Compressed Air to Tools, Hoists, Blowing and Spraying Services, Motors and Presses. Pilot Controls. Pressures and Amounts of Air Employed

AIR AS A MEDIUM of pressure transmission acts quickly and smoothly and its control is comparatively simple hence it finds an ever widening use in the operation of tools especially for contractors in tunnels where steam cannot be permitted and where supply of air to operators is a factor.

Air for Rock Drills

Pressures employed on rock drills range from 60 to 100 lb. while those used on industrial tools and machines range from 70 to 90 lb. Pneumatic hammers operate best at between 80 and 90 lb. pressure and pneumatic drills at about 90 lb. pressure.

Air consumption of a single rock drill for various sizes is indicated in Table I. To find the amount of free air required by a number of drills supplied from the same compressor, multiply the air required by one drill, as given in Table I, by one of the following factors:

Number of drills.	2	3	4	5	6	7	8	9	10
Factor (a)	1.8	2.7	3.4	4.1	4.8	5.4	6	6.5	7.1
Number of drills.	12	15	20	25	30	40	50	60	70
Factor (a)	8.1	9.5	11.7	13.7	15.8	21.4	25.5	29.4	33.2

Values given in the tables are intended for fair conditions in ordinary hard rock. In soft material, where the actual time of drilling is short, more drills can be run with a given size compressor than when working in hard material, when the drills would be working continuously for a longer period of time, thereby increasing the chance of all drills operating at the same time.

In tunnel work, where the rock is hard, experience shows that more rapid progress has been made when the drills were operating under a high pressure and it has been found profitable to provide compressor capacity in excess of the requirements by about 25 per cent.

Pneumatic Tools

Consumption of air required by pneumatic tools of various kinds is indicated in Table II. At altitudes other than sea level, corrections for change in density of the air must be made as indicated in the section on Compressed Air Distribution in this issue.

Applications of air for operating tools, which indicate convenience and adaptability, are shown in Figs. 2,

TABLE I. CUBIC FEET OF FREE AIR REQUIRED PER MINUTE BY ONE ROCK DRILL

Gage pressure, lb. per sq. in.	Cylinder diameter of drill, inches												
	2	2¼	2½	2¾	3	3⅛	3⅜	3⅛	3½	3⅝	4¼	5	5½
60	50	60	68	82	90	95	97	100	108	113	130	150	164
70	56	68	77	93	102	108	110	113	124	129	147	170	181
80	63	76	86	104	114	120	123	127	131	143	164	190	207
90	70	84	95	115	126	133	136	141	152	159	182	210	230
100	77	92	104	126	138	146	149	154	166	174	199	240	252

TABLE II. AIR CONSUMPTION OF PNEUMATIC TOOLS

Chipping hammers..	Weight, lb.	5	7	8	9	10	11	12	13	14	18
	Cu. ft. per min.	6	10	12	13	15	17	18	20	20	22
Hoists, direct lift....	Cylinder diam., in.	6	8		10	12		14	17		19
	Cu. ft. per ft. lift (2-to-1 lift)	0.8	1.5		2.2	3.3		4.7	6.6		8.1
	Cu. ft. per ft. lift (4-to-1 lift)	0.4	0.7		1.5	1.7		2.4	3.0		4.0
Geared hoists..... ..	Capacity, tons	1	1½	2	3	4	5	6	8	10	12½
	Cu. ft. per ft. lift	3	5	6	8	10	15	20	25	30	40
Jacks.....	Cylinder diam., in.	8	10		12	14		16	20		24
	Cu. ft. per ft. lift	1.8	2.8		4.0	5.4		6.9	11.1		15.8
Motors.....	Horse power	2			4			5	8		15
	Cu. ft. per min.	40–50			60–75			90–100	125		240
Pile hammers.....	Weight, lb.	145		640		1500		5000			7500
	Cu. ft. per min.	100		150		200		350			600
Hand riveters.....	Size, lb.	13	14–15		16–17	19–20		21–22		23–25	
	Cu. ft. per min.	16	18		20	22		24		25	
Rotary drills.....	Weight, lb.	10	15	20	30	35	40	45	50	60	70 75
	Cu. ft. per min.	15	18	20	25	27	30	35	40	43	45 48
Rotary flue rolling, reaming and tapping machines.	Weight, lb.	30		40		50		55		65	130
	Cu. ft. per min.	20		25		30		35		35	45
Sand blast (80 lb. pressure).	Size nozzle, in.	3/16			¼			5/16			½
	Sand per hour, lb.	500			900			1700			3000
	Cu. ft. air per min.	45			85			190			340
Hand sand rammers.	Weight of tool, lb.	7			18			24			30
	Cu. ft. per min.	9			15			20			25
Suspended sand rammers.	Weight, lb.	280			325			370			925
	Cu. ft. per min.	50			90			100			130
Stone-carving tools..	Weight of tool, lb.	1		2		3		4		5	9
	Cu. ft. per min.	3–6		4–7		5–8		6–9		7–10	12
Wood-boring machines.	Weight, lb.	10					15				30
	Cu. ft. per min.	15					20				25

TABLE III. AIR CONSUMPTION OF COMPRESSED-AIR HOISTING ENGINES

Cyl. diam., in.	Stroke, in.	R.p.m.	Nominal h.p.	Actual h.p.	Weight lifted by single rope	Free air per min., cu. ft.
5	6	200	3	5.9	600	75
5	8	160	4	6.3	1,000	80
6¼	8	160	6	9.9	1,500	125
8¼	10	125	15	12.1	2,000	151
7	10	125	10	16.8	3,000	170
8¼	12	110	20	18.9	5,000	238
10	12	110	25	26.2	6,000	330

3 and 4. Air also finds convenient use in connection with the operation of machine tools in such uses as in air chucking. It is applied to not only ordinary chucks but collet and milling-machine chucks and to a number of special tools. By decreasing the amount of labor required in operating a machine tool, application of pneumatic appliances betters production by decreasing time and labor and increasing accuracy of operation.

Supply systems for air tools include receivers discussed in the section on Compressed Air Storage Methods elsewhere in this issue and compressors using steam, gasoline or oil as motive mediums. Gasoline and Diesel oil engines are used extensively for portable outfits such as shown in Fig. 5.

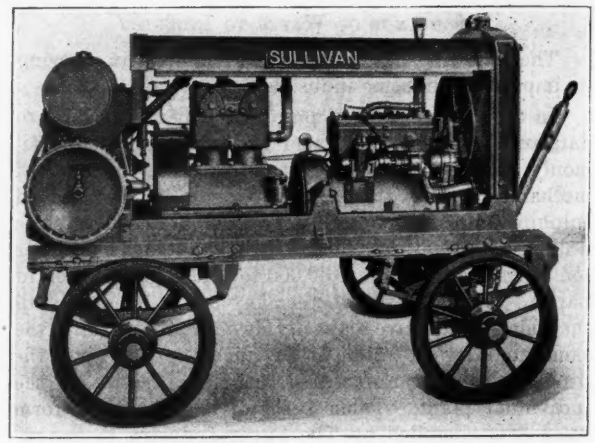


FIG. 5. PORTABLE AIR COMPRESSOR EQUIPMENT MOUNTED WITH RUBBER TIRES

Wrapped and braided hose for conveying compressed air from its source to the tools is made up of an inner tube, reinforcement of plies of cotton duck, an outer rubber cover and a protective covering of wire armor or a woven cotton jacket. Test pressures in pounds per square inch for different weights of jackets ranging from ¾ to 3 ounces per lineal foot are:

W.	¾	⅞	1	1¼	1½	2	2¼	2½	3
T. P.	750	725	700	650	650	600	600	550	550

The minimum wall thickness for the rubber tube generally adopted is $\frac{3}{32}$ in. and that for the rubber cover for both wrapped and braided hose is $\frac{1}{16}$ in.

Pneumatic Hoists

Compressed air can be used in any engine that will operate with steam hence finds application in hoisting engines for mining or for work of a temporary or intermittent character in which case the air is compressed usually to 60 lb. pressure and the free-air consumptions of single-cylinder engines is given in Table III.

Pneumatic hoists are used for short lifts in places where compressed air already is installed. The movable hoist is limited by its flexible air connection to a radius of about 25 ft. The hose connection is suspended in

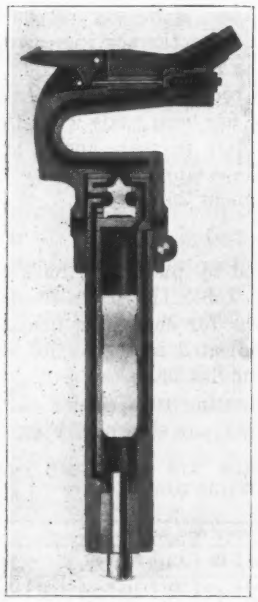
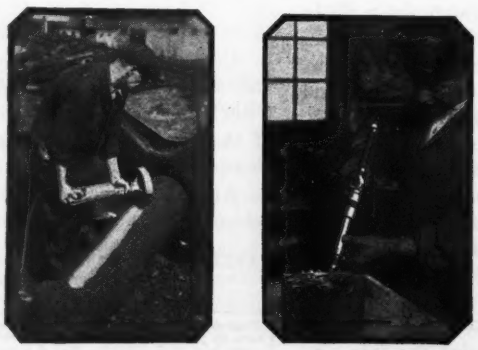


FIG. 1. HEAVY-DUTY PNEUMATIC CHIPPER



FIGS. 2 AND 3. PORTABLE TOOLS OPERATED BY COMPRESSED AIR: FIG. 2 SHOWING ROTARY GRINDER IN OPERATION AND FIG. 3, PENCIL GRINDER USED IN FINISHING A STEEL DIE

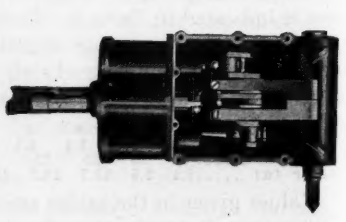


FIG. 4. CLOSE-QUARTER DRILL MAKES DRILLING IN DIFFICULT PLACES, AN EASY MATTER

loops from trolleys which run on I-beams or cables as shown in Fig. 6. The direct-acting hoist is made with a stroke of from 4 to 20 ft. but with rope and sheaves it may be geared to 2 to 1 or higher ratio.

Arrangement on Crane Depends on Head Room

Where headroom is unrestricted the hoist, which is usually single acting, is installed vertically on the crane but where head room is limited it is placed horizontally as shown in Fig. 7. Such air hoists usually are made double acting as shown in Fig. 8. The double-acting or balanced-pressure hoist has the motive end of the cylinder under constant pressure and the balancing end subject, at will, to a variation of from full to no pressure. The force exerted by the hoist is due to the difference in pressures on the two sides of the piston.

FIG. 6. AIR HOSE IS SUSPENDED FROM TROLLEYS RUNNING ON THE I-BEAM FLANGES

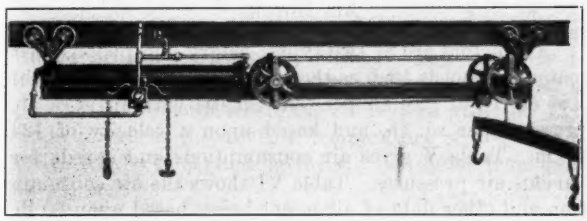


FIG. 7. PNEUMATIC HOIST FOR SITUATIONS WHERE HEAD ROOM IS LIMITED

As the area of the piston rod makes the effective area on the two sides unequal, the piston is forced toward the stuffing box when the air pressure is equal on the two sides. The hoist is operated by chains connected to a controlling valve. Special automatic attachments are supplied when the load is suspended for a period of time and speed boxes are used to govern the speed of stroke independent of the operator. Air consumption and other operating data of direct-acting pneumatic hoists based upon 80 lb. pressure and allowing no loss for leakage or slip are given in Table IV.

Air-motor hoists are also employed by gearing a high-power air motor through a mechanical train to the hoisting drum. Less air is required for operating air-motor hoists than for those of the cylinder-and-piston type, about 1.85 cu. ft. of free air being required to raise 1 t. 1 ft. high based upon 230 cu. ft. to lift 2000 lb. at 124 ft. per min. with 80 lb. pressure.

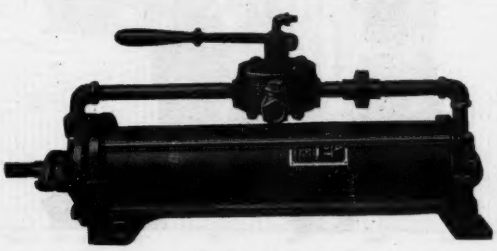


FIG. 8. DOUBLE-ACTING BRACKETED AIR HOIST FOR HORIZONTAL INSTALLATION ON CRANE

Lift speed increases with the air pressure, also consumption of free air but high pressures are more economical than low pressures in proportion to the power delivered since air consumption increases with pressure more slowly than hoisting speed.

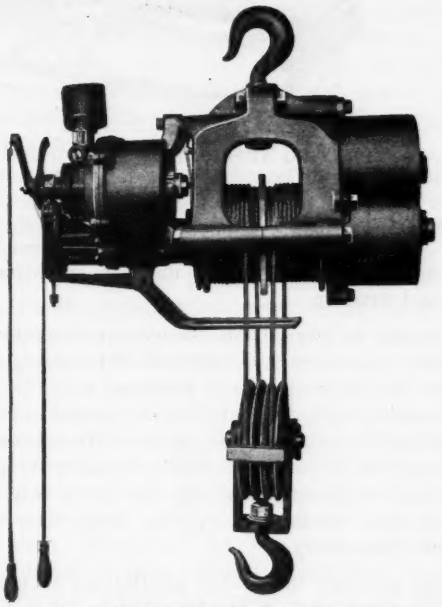


FIG. 9. AIR-MOTOR-DRIVEN HOIST

Application of compressed air for blowing processes includes cleaning services such as boiler-tube cleaning, cleaning of machines and surfaces in industrial processes and agitation of fluids.

Air Mixes As Well As Sprays Paint

Spraying is not entirely dependent upon injection to project the paint on the surface but employs direct air pressure in the paint container itself. The air, under pressure, forces the paint through the hose line direct to the gun, materially reducing the volume of air required for forming the spray. Air passing up through the paint not only agitates the paint, keeping it at a

TABLE IV. AIR CONSUMPTION OF DIRECT-ACTING PNEUMATIC HOISTS BASED UPON 80 LB. PRESSURE AND NO ALLOWANCE FOR LEAKAGE AND SLIP

Nominal diam. of hoist, in.	Vertical and horizontal hoists,				Double-acting rope-geared hoist,			Double-acting rope-geared hoists,								
								Rope-geared 2 : 1			Rope-geared 4 : 1			Rope-geared 6 : 1		
	Capacity, lb. (10 per cent. friction)	Cu. ft. free air to lift hook 1 ft.	A_1, in., for vert. hoists	A_1, in., for hor. hoists	Capacity, lb. (20 per cent. friction)	Cu. ft. free air to lift hook 1 ft.	Approx. length A_1, in.	Capacity, lb. (25 per cent. friction)	Cu. ft. free air to lift hook 1 ft.	Approx. length A_1, in.	Capacity, lb. (25 per cent. friction)	Cu. ft. free air to lift hook 1 ft.	Approx. length A_1, in.	Capacity, lb. (32 per cent. friction)	Cu. ft. free air to lift hook 1 ft.	Approx. length A_1, in.
4	861	0.54	61	58	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
5	1,356	0.85	63	58	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
6	2,050	1.22	67	59	900	0.61	72	800	0.61	139	400	0.30	139	250	0.21	134
7	2,791	1.73	67	59	1,200	0.87	75	1,050	0.87	139	525	0.43	139	325	0.29	134
8	3,616	2.24	68	61	1,600	1.12	75	1,450	1.12	145	700	0.56	145	450	0.38	137
9	4,592	2.85	68	61	2,000	1.43	78	1,900	1.43	146	950	0.71	146	575	0.47	142
10	5,636	3.29	72	62	2,500	1.70	81	2,400	1.70	147	1,150	0.82	147	750	0.55	142
12	6,154	5.06	72	62	3,600	2.55	82	3,500	2.53	152	1,400	1.25	148	1,100	0.84	148
14	11,270	7.13	76	64	5,000	3.57	88	4,800	3.57	155	2,400	1.78	153	1,500	1.17	153
17	16,500	10.10	77	65	7,000	5.05	91	7,000	5.05	161	3,500	2.50	154	2,250	1.67	154
19	20,900	12.50	78	65	9,000	6.25	93	9,000	6.25	161	4,500	3.10	154	2,900	2.10	154

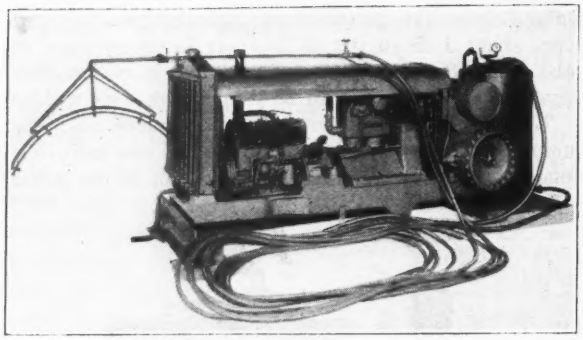


FIG. 10. SPRAYING APPLICATION FOR PIPE LINE

uniform consistency without settling but, due to the heat of compression, the paint mixture is kept constantly at a temperature that permits uniform operation both winter and summer.

As shown in Fig. 10 one spray gun consists essentially of a pipe curved to conform with the pipe to be painted. The curved pipe is provided with five spray jets through which the paint is discharged normal to the surface of the pipe line. A crew of nine men can coat completely 1½ to 2 mi. of 2½ ft. diameter pipe in 9 hr. Individual control of the five spray tips is provided so that the amount of flow from each can be adjusted if necessary.

Spray painting finds wide application in manufacturing processes such as machine finish. Not only are machine parts painted in this manner but fine finishes such as those on automobiles, refrigerators and fine furniture are now applied by this method. Air-motor-driven agitators are provided with cellulose lacquer spraying equipment and for other materials requiring continuous agitation while electric heaters are furnished as auxiliary equipment when varnish, which requires heat to produce a proper finish, is sprayed.

Sprays are used also for humidification purposes and

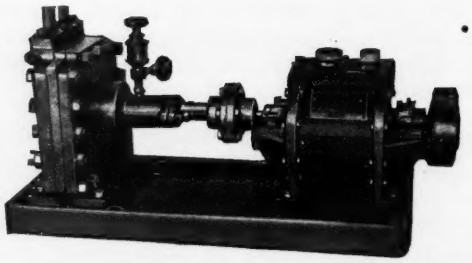


FIG. 11. AIR ENGINE DIRECT CONNECTED TO BLOWER

for moistening textile fabrics and applying oil films to sheet metals in various production processes.

Paint spraying equipment requires about 6 cu. ft. of air per min. at pressures ranging from 35 to 50 lb. per sq. in. for most materials and 60 lb. pressure for exceptionally fast work or for heavy material. The actual power required is about one horsepower for each ordinary spray gun used. The material tanks, holding the paint supply, are usually of about 5-gal. capacity and kept under a pressure of about 20 lb. per sq. in.

Air Motors

Air motors are of two types: rotary and piston. Air motors for hoists such as that shown in Fig. 11 use about 1.85 cu. ft. of free air per ton-foot lift with air at 80 lb. pressure per sq. in. and based upon a velocity of 124 f.p.m. Table V gives air consumptions and speeds for various air pressures. Table VI shows the air consumption and other data of air-motor hoists based upon 80 lb. pressure per sq. in. with no allowance for leaks or slip.

In some situations, such as in tunnel work, where steam cannot be employed, air-operated motors find particular application; also they find application for operating machines of various kinds. Many air motors are reversible and may be driven by air or steam. Motors of this kind are available in sizes ranging from ½ to 30 hp. based upon 90 lb. air pressure. They are especially applicable in locations where space is limited and they

TABLE V. AIR MOTOR HOIST DATA

Load Lb.		Pressure Lb. Sq. In.			
		50	60	70	80
3-hp. motor	A	68	94	117	137
1000	S	37	80	110	132
7½-hp. motor	A	160	195	229	260
1000	S	126	157	174	161
	A	130	195	225	254
1500	S	71	117	136	150
	A	112	155	194	230
3000	S	26	64	94	124

A is air consumption cu.ft. per min.

S is rope lift speed, ft. per min.

TABLE VI. AIR CONSUMPTION BY AIR-MOTOR HOISTS BASED UPON 80 LB. PRESSURE WITH NO ALLOWANCE FOR LEAKS

Capacity lb.	Max. lift ft.	Feet lifted per min. at 80 lb. pressure	Cu. ft. free air per min.	Shortest distance bet. hooks A	Length in in., B	Width in in.	Weight lb.
1,000	20	32	45	33	25	16	270
2,000	20	16	45	33	25	16	270
4,000	20	8	45	40	33	21	395
7,000	20	8	80	47	40	30	785
10,000	20	7	80	47	40	30	785

FIG. 12. INTERIOR VIEW OF A TWIN-CYLINDER AIR MOTOR FOR DRILLING MACHINES

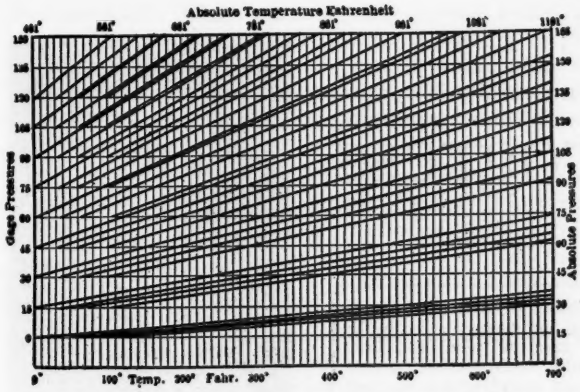


FIG. 13. CHART SHOWING INCREASE OF PRESSURE BY REHEATING

can be operated equally well in any position. Air motors are also used to operate dampers of various kinds.

Reheating Compressed Air

After the warm compressed air leaves the compressor and receiver and has passed through the transmission lines to the point of use, it becomes cooled to approximately the temperature of the surrounding atmosphere thus representing a loss in volume. This loss may be overcome by use of a suitable reheater placed as near as possible to the point where the air is to be utilized. It is usual to reheat the air to a temperature of 250 deg. F. which results in expanding the air in volume from 30 to 35 per cent.

Increase of Pressure by Reheating

Pressure changes in reheating air are shown in Fig. 13. The lowest group of 4 lines is for air starting from pressure of 0 lb. gage, for initial temperatures of 100, 60, 32 and 0 deg. F., reading from the bottom upward. The next 4-line group is for starting pressure of 15 lb. and for the same temperatures as before. A group of lines is given for each 15-lb. pressure up to 120 lb.

Increase of Volume by Reheating

In Fig. 14, which shows the effect of reheating air on the volume of the air, the initial temperatures are taken as before but the pressures remain the same during the operation represented. The relative volume at any temperature is indicated by the height of the vertical line corresponding with that temperature, the height AB to CD representing one volume and each horizontal line above that indicating, successively, an additional $\frac{1}{10}$th volume. When the line EF at the top is reached, the

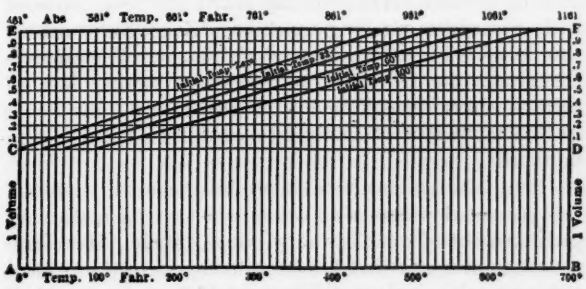


FIG. 14. CHART SHOWING INCREASE OF VOLUME BY REHEATING

original volume has been doubled. Figures below the base-line AB indicate the sensible temperatures and figures above the upper line indicate the corresponding absolute temperatures.

Pilot Controls

Modern manufacturing plants make many uses of compressed air apparatus that must be controlled carefully. Resort is made frequently, therefore, to the use of pilot controls which are delicately regulated but which make possible rapid and direct action by compressed air or indirect action through the intervention of a supplementary fluid of some other kind.

Automatic temperature control by pneumatic means for operations involving heat, either for room warming or industrial heating purposes, opens a wide field for the use of pilot yalves. A new machine, which had its inception in the rubber industry but through its success which is now spreading into many industrial fields, the cycle controller, regulates the pressure through pilot valves at 15 or 20 lb., admitting this air to diaphram-operated valves which in turn admit high-pressure air, water or steam, according to the medium required. Application of this principle is shown in Fig. 15.

The vulcanizers usually have three or four operations to perform after they have been loaded to begin a cure and then the cure must be maintained for a predetermined time. These three or four operations, which are now regulated by cycle controllers, are performed in the reverse order before the finished work is withdrawn from the vulcanizer. Likewise, action of a large variety of machines used in manufacturing processes may not only be controlled with precision but with safety, through equipment furnished with interlocking devices.

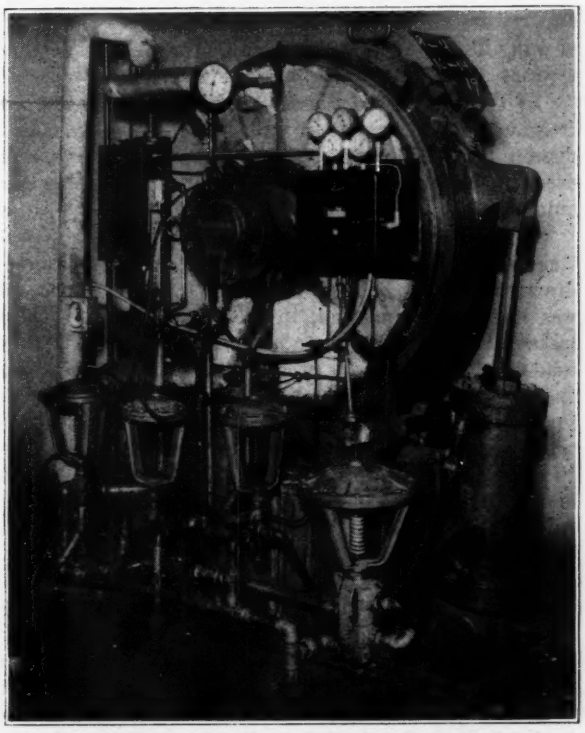


FIG. 15. COMPLETE CYCLE CONTROL ON AUTOMOBILE-TIRE PRESS

Power Use and Human Progress

By Harry W. Benton

Mr. Benton has learned in the school of experience, supplemented by individual study and correspondence courses in steam, mechanical and electrical engineering. From 16 yr. of age, he has been in power plants as operator, installation man and plant engineer. His range of experience covered steam machinery, high-pressure hydraulic work and factory arrangement. For 3 yr., 1916-19, Mr. Benton was plant engineer for Russell Motor Car Co. on production of shells and gun mounts; then, for 7 yr., he was maintenance engineer for Willys-Overland Co.; and for the last 4 yr., has been plant engineer for Pratt & Whitney Co.

NO MATTER how far back we look into the history of human progress, we find traces indicating the activity of mind. Even in the Stone Age, workmen left traces of tools or implements suited to reduce labor. Each generation has been faced with ever-increasing population and has been alert to find ways and means whereby the increasing necessities of human existence could be met.

It is, however, interesting to note that the progress of the last 50 yr. is without question the most remarkable that has ever been known, due to increased application of power to replace muscular effort.

It took something over one year to lay the first cable across the Atlantic but today a submarine cable can be laid across the Atlantic in the comparatively short time of about two weeks. The difference between one year and two weeks represents the saving in cost as the result of applying power to overcome the obstacles which were associated with the laying of the first cable.

In transportation, the railroad for the hauling of freight and passengers and the automobile for local and distant travel influence practically every business and every home in America by substitution of power for animals.

Only a few years ago, all street and highway construction was done by hand and with the use of horse-drawn vehicles. Ditches were dug by hand; concrete was mixed by hand and, in fact, each of the various tasks in road building was a manual labor job. The first road-making machinery was powered with the steam engine and boiler. These had their limits and they, in turn, have been replaced by the internal combustion type of engine. What was an insurmountable obstacle 10 yr. ago is today nothing. Road-making machinery is brought into play and in a seemingly short time the hill has been leveled into the valley and a highway with beautiful sweeps and grades is a reality.

This same progress is evidenced in every walk of life. Because men visualized the possibilities of a large power station serving many industries, it is possible to supply the small manufacturer with low-cost power and we are today realizing the development of that idea. The growth in the development of electrical machinery and in the application of electricity to a limitless number of uses has come about in the space of approximately 50 yr. Industry is almost universally powered with electric motors today. We have safer shops and factories in which to work; our shops are easier to keep clean. The modern manufacturing plant is of one-story construction and covers large areas, thus reducing handling costs and materially reducing the hazards when handling heavy machinery, because of the fact that it is handled by power on one floor rather than from one story to another.

These single-story buildings of large floor area are possible primarily because of the ease with which they can be illuminated by electricity during the dark morning and evening periods of the working day. Before the time of electric light, manufacturing buildings had to be narrow and multi-storied to make it possible for daylight to be used for the longest possible period, because artificial lighting available was unsatisfactory.

In steam-power stations, hand-firing methods have been replaced with mechanical stokers and with pulverized fuel. Transportation of materials from one department to another in all industry is performed by some type of truck. In the office, we find power-driven or mechanically operated bookkeeping machinery, tabulating machinery and adding machinery. No matter what industry we examine, we find that out of the minds of men has come power-operated machinery developed primarily to reduce manual labor, increase the productivity per man and thereby reduce the cost per piece of the material manufactured.

The average American home offers a striking example of power-driven mechanical equipment to replace muscular effort. The broom has been replaced with a vacuum cleaner. The rubbing board has been replaced with a modern washing machine. Even dish-washing can be done by electric power equipment. The home is electrically lighted and the American mother has all sorts of electrical equipment for health and convenience so that manual work in the home has been reduced to a minimum.

That labor-saving machinery has been the cause of the present depression and that labor-saving machinery puts men out of work is, to my mind, untrue. If we consider the progress that has been made up to the present time, we ask ourselves, "What would have happened, if we had not developed this progress?" Our population

has increased. What would be our condition today, if we tried to exist in the same manner as we did 25 yr. ago? Answers to these two questions would seem to indicate that it would be impossible to live today with our present population under the same conditions as people lived 50 yr. ago.

There has been continual movement of people from the country to the city, increasing requirements for transportation, communication, sanitation, food supply. We find, therefore, that the very actions of men have developed new conditions so that instead of men developing new devices merely to satisfy a personal desire to develop something out of which they ultimately might reap a profit, they were urged forward in the development of these various devices because the changing conditions from day to day presented new problems and new requirements to be met.

In meeting these requirements, factories have grown not only in number but in size, power application and output per worker have increased, so that the American working man is the highest paid of any in the world.

His home life from the standpoint of comfort cannot be equalled. This condition results, not from labor-saving machinery putting men out of work but from the construction of manufacturing plants, from the enlargement of existing manufacturing plants and from the continued industrial activity which this nation has developed and will continue to develop in the manufacturing of labor-saving machinery and its further application to the problems of doing more work and in a greater multitude of places for the betterment of the American people.

That these statements are true can best be proved by a comparison of statistics:

Value of American manufactured products, fifty years ago	$ 7,000,000,000
Last year almost	70,000,000,000
American industrial wage earners, fifty years ago	2,750,000
In 1929 about	8,750,000
American industrial payroll, fifty years ago	1,000,000,000
In 1929 almost	11,000,000,000
Power used by industries, fifty years ago, hp.	4,000,000
In 1929 about	38,000,000
Population of America, fifty years ago	60,000,000
The 1930 census shows about	120,000,000

Development presented in the foregoing is the positive outcome of labor-saving machinery and the better application of power, both mechanical and electrical to the doing of things which previously were done manually.

In all civilization, the biggest factor and the most potential is the Human Mind. The mind of man will never cease in developing new ways in which to make further application of power. Progress, made possible by the better and broader use of Power, has only just begun. Possibilities of progress for the future are beyond today's imagination.

Electric Motors for Industrial Plant Drives

DIRECT CURRENT MOTORS, TYPES AND CHARACTERISTICS, VOLTAGES, SPEED CONTROL, EFFICIENCIES, CONSTRUCTION

IN THE APPLICATION of electric motors to machinery in industrial plants it is essential that motors of the proper type and characteristics be selected for the machinery which is to be driven, in other words, the characteristics of the motors must be suited to the characteristics of the load.

All motors, of course, are either of two main classes, direct current motors and alternating current motors. As a rule, there is little choice in the matter of which of these two types is to be used as this consideration, usually, is fixed by the kind of current available.

Direct current motors may be grouped according to types; shunt wound motors, series wound motors and compound wound motors. Compound motors can be further classified according to whether they are of the cumulative compound type or the differentially compound type.

Each of these three types of direct current motors has characteristics peculiar to itself. The shunt wound motor meets the requirements of a large range of industrial applications, for the constancy of speed over a wide range of load, is desirable for many types of machines. The torque curve is a straight line over the ordinary working range and the efficiency remains high over a considerable load range, with little change from 75 per cent load to 125 per cent load. The characteristics possessed by the shunt motor render it the best suited direct current motor for the majority of constant speed drives.

Series motors have a more limited field of applica-

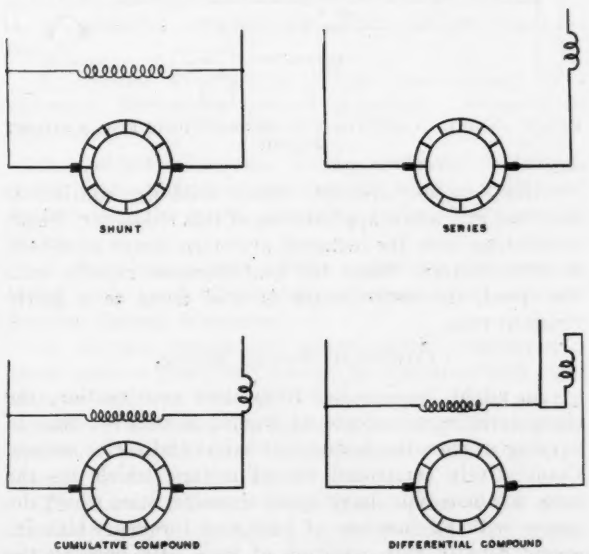


FIG. 1. DIAGRAMS OF VARIOUS TYPES OF D. C. MOTORS

tion, but their peculiar torque characteristics make them extremely adaptable for certain applications. In the series motor the torque increases as the speed decreases. Increase in current in a series motor increases the torque directly due to the increased armature current and also by strengthening the field magnetism. Therefore, the torque of this motor is extremely high under heavy loads. The standstill torque of a series motor may be several times full load torque. Heavy overloads may be handled successfully without injurious sparking.

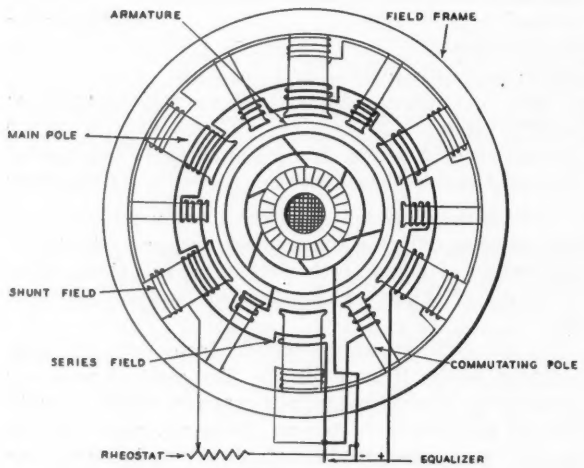


FIG. 2. COMMUTATING POLE MOTOR

The largest single application of the series motor is for electric traction, this type of motor being used on all street cars. For similar industrial work such as on cranes or hoists, the series motor is nearly always used if direct current is available, where the variation of speed with load is particularly desirable. For instance, when lifting a heavy piece with a crane, it is usually desirable to proceed slowly. When running light it should be possible to make considerable headway to cover the ground rapidly.

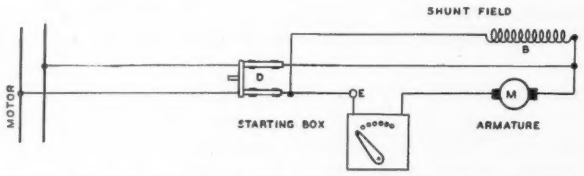


FIG. 3. CONTROL APPARATUS CONNECTIONS FOR A SHUNT MOTOR

Series motors are not widely used for continuous duty but find a few applications of this character. Small ventilating fans, for instance, are often direct connected to series motors. Since the load increases rapidly with the speed, the series motor is held down to a fairly constant rate.

Compound Wound Motors

As might be expected from their construction, the characteristics of compound wound motors combine in varying degrees the features of shunt and series motors. Cumulatively compound wound motors, which are the more common type, have speed characteristics which decrease with an increase of load and torques which increase rapidly with addition of load. By varying the ratio between the number of series and shunt ampere turns, the characteristics of compound motors can be varied between considerable limits. Some motors are built with about 10 per cent shunt ampere turns, merely to prevent the motor from running too fast at light loads. Others are built with as low as 10 per cent series ampere turns. Ordinarily about 20 per cent of the ampere turns at full load are in the series coil and motors are said to be 20 per cent compounded.

The compound motor shares with the series motor to some extent, the ability to develop high torque per ampere in starting. It is essentially a fairly constant speed motor with excellent pulling power on heavy loads and good starting power.

In a differentially compounded motor, the magnetomotive force of the series field opposes that of the shunt field, thus weakening the resultant field with an increase in load. The object is to compensate for the armature drop, thus maintaining the speed constant at all load, and if not overloaded, these machines may operate satisfactorily but as a rule their operation is unstable and they are not much used.

Compound wound motors are used extensively for elevator service and for many similar applications where a heavy starting torque and fairly constant running

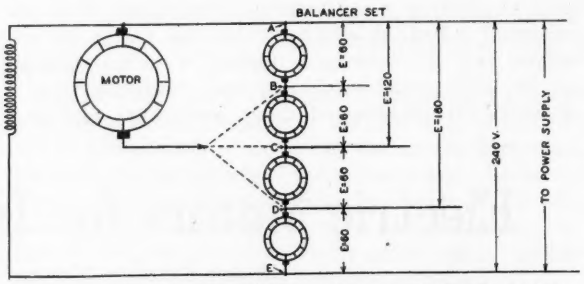


FIG. 4. SCHEMATIC DIAGRAM OF A MULTI-VOLTAGE CONTROL SYSTEM

speed are required. In industrial plants they find wide application in the driving of pumps, compressors, shears, presses, reciprocating tools and similar machines where irregular loads with severe peaks are encountered together with a demand for fairly constant rotative speeds. Compound motors should be applied where high starting effort with low current is desired and where some change of speed with load is not objectionable. They are also useful on circuits with fluctuating voltages in which case the series field winding of such motors helps to steady the current and speed.

In this discussion of types of d.c. motors, we have considered only the basic differences of motors, not their constructional differences. In each of the three classes considered, there are modifications which impart varying characteristics, depending upon which is required. In the case of shunt and compound motors for instance, where motors are subject to wide variations in load and where the consequent shifting of the plane of commutation trends to promote sparking, the so-called commutating pole motor has been developed. In this type of motor, a number of "interpoles" are added midway between the main field poles as shown in Fig. 2. These interpoles perform two functions, they neutralize the magnetizing influence of the armature and thus prevent the existence of a cross field in the zone of commuted

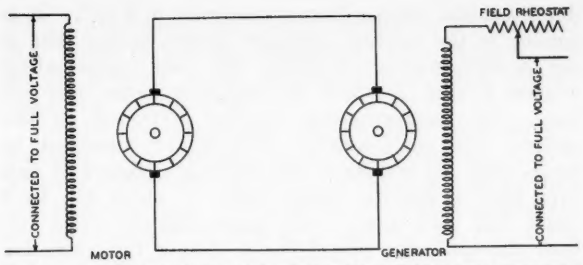


FIG. 5. CONNECTIONS FOR VARIABLE VOLTAGE SYSTEM OF MOTOR SPEED CONTROL

coils and they create a field in this zone to cause sufficient voltage to be generated in the commutated coils to overcome the effects of self induction and to assist in reversal of current flow. Since both of these functions demand that the interpole strength vary in direct proportion to the load current, the interpole windings are connected in series with the armature.

Speed Control

The current taken by a direct current motor is due to the difference between the impressed voltage and the voltage generated by the armature, that is the counter electromotive force. Since the counter electromotive force is a function of the speed, it is evident that the current consumption of the motor will vary according to the speed; the higher the speed, the lower the current consumption. When a direct current motor is at rest, there is, of course, no counter electromotive force being generated and since the armature resistance is very low, if full voltage were impressed upon the machine in this condition a destructive current would flow.

It is necessary, therefore, in starting d.c. motors, to introduce resistances into the circuit which limit the initial flow of current and which are cut out of the circuit as the motor accelerates and builds up a counter electromotive force. In practice, therefore, a rheostat is provided, the resistance of which is divided into sections which are cut out of the circuit as the motor comes up to speed.

In the case of a shunt or compound wound motor, the shunt field is so designed that it is connected directly across the line, hence, in providing a starting rheostat, the arrangement used must be such as to place the rheostat in the armature circuit only. The circuit is shown in Fig. 3.

Such a resistance in the armature circuit can, of course, be used for purposes of obtaining speed control but when used in this way, the rheostat should be designed so as to handle the full current to the motor for indefinite periods. This method of control is useful only in obtaining speeds below normal. If it is desired to attain speeds above rated normal, a rheostat is introduced into the field circuit.

Armature current control by means of rheostats is suited for highly intermittent duty, but because of poor efficiency and fluctuating speed tendencies, the application is limited. It is not suited for machine tool drives where changing loads are involved and exact, constant speeds are desired. It is used extensively for traction service, cranes and hoists, operations where speed is under manual control. It is used for printing presses and elsewhere for slow speed "setting up" work where the motor normally operates at higher speeds. It is applied quite regularly for blowers and fans, where the load is steady and the maximum motor capacity is required at high speed but where, at low speeds, the losses are greatly reduced because of the lesser loads.

Other methods of speed control in direct current motors make use of means for bodily shifting the position of the armature with respect to the field poles and in varying the voltage impressed upon the motors by the use of balancer sets or by interposing a motor generator set between the line and the motor. The first method referred to is effective but since it requires motors of special construction (for this relative movement between the field poles and armature is, of course, accomplished by mechanical means), it is used only for special drives. It is in extensive use on a variety of machine tools.

The multi-voltage system is shown in Fig. 4 while the principle involved in the motor generator scheme is shown in Fig. 5. Both schemes are self evident.

In the latter system, the voltage produced by the generator is varied by manipulating the field rheostat and this variable voltage is impressed upon the motor.

Efficiencies of D.C. Motors

As a rule, the efficiency of electric power equipment is high. A 1-hp. motor has an efficiency of about 65 per cent, a 5-hp. 75 per cent, a 10-hp. 92 per cent and a 20-hp. 88 or 89 per cent. A 500-kw. machine may have an efficiency of 94 per cent.

In any machine, whether it be a motor, generator or transformer, the efficiency is the ratio of the output to the input and is expressed as, Efficiency = Output ÷ Input. Thus, in order to determine the efficiency of a motor, it is necessary to take simultaneous measurements of its input and output.

Alternating Current Motors

Types and Characteristics, Speed Control, Motor Troubles and Tests

IN GENERAL, ALTERNATING current motors may be classified according to three distinct types as follows:

1. Synchronous motors. These are ordinary synchronous alternating current generators, reversed in function.

2. Induction motors, having armature windings, closed upon themselves or through local circuits and connected to the source of supply and without commutators.

3. Repulsion motors, having armatures with commutators and brushes connected through local circuits wherein current is induced.

4. The a.c. commutator motor, which is similar to a direct current generator, having an armature with commutator and field winding both connected to the supply circuit. The repulsion motor really belongs to this class but is different in that the armature is not connected directly to the line.

There are, in fact, three different types of a.c. commutator motors, i.e., series, repulsion shunt and shunt induction motors.

In addition to the above classification, a further differentiation of a.c. motors is based upon the fact that either of the first two types and sometimes also the third may be operated by single, two or three-phase currents.

Of these various types of motors, the polyphase induction motor is perhaps the most used. Its inherent simplicity, its ruggedness and its reliability lend it well to many types of drives, and it finds great application in industrial service. Single-phase induction motors are used to a certain extent for small drives, but are more expensive to construct than the polyphase type and for large motors only the polyphase type is in general use.

The synchronous motor is essentially an a.c. generator. Any modern a.c. generator will operate more or less satisfactorily as a synchronous motor and unless special operating features must be provided for, the two are often identical in construction.

There are two advantages with the synchronous motor, first, it operates at a constant speed at all loads,

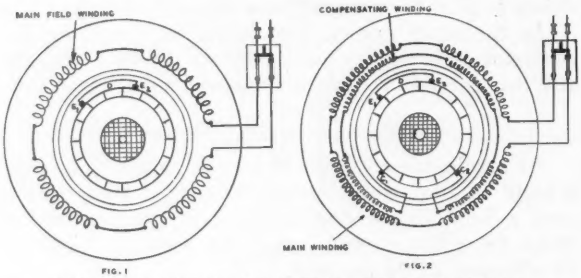


FIG. 1. DIAGRAM OF THE REPULSION MOTOR
FIG. 2. DIAGRAM OF THE REPULSION-INDUCTION MOTOR

provided the driving alternator runs at a constant speed and, second, its power factor is at all times under the control of the attendant; it can be used to correct low power factor of the system that feeds it in addition to driving a mechanical load, provided it has sufficient capacity.

While these advantages of the synchronous motor are much to be desired, they are offset to a certain extent by certain disadvantages. First, the synchronous motor can not be used profitably in sizes below 100 hp. except in the case of small motor generator sets. Secondly, it is not adapted to applications requiring frequent starting and stopping. The synchronous motor is inherently a constant speed machine and cannot be used where a variable or adjustable speed is required unless some mechanical means of changing the speed is provided.

As stated previously, the repulsion motor has an armature which is like that of a direct current machine. As shown in Fig. 1, this armature is provided with two brushes E_1 and E_2 which are inclined to the axis of the stator winding. These brushes are connected by a low resistance conductor D, which short circuits the armature. A machine of this type has a high starting torque with a small starting current, and a rapidly decreasing torque with decreasing speed; being similar in this respect to a direct current series motor. The power factor of the repulsion motor increases with the speed, and near synchronous speed, it attains a value much higher than is generally obtained in induction motors. These motors are used principally for constant torque applications such as printing press drives, fans and blowers

Another type of repulsion motor is the repulsion induction motor, shown diagrammatically in Fig. 2. It is similar to the straight repulsion motor, except that it has a compensating winding, and two compensating brushes C and C_2 which the repulsion motor does not have. The compensating winding is wound on the stator. The compensating brushes are connected in series with the compensating winding. Motors of this type have a starting torque equal to about 2½ to 3 times full load torque with approximately twice full load current. The power factor, due to the corrective

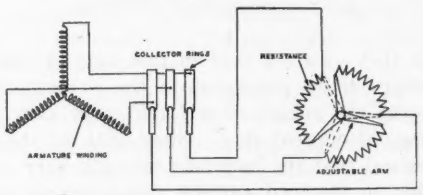


FIG. 3. SPEED CONTROL OF WOUND ROTOR INDUCTION MOTOR BY SECONDARY RESISTANCE CONTROL

action of the compensating winding, is very high at all loads but the efficiency is lower than that of the induction motor. Single-phase motors of this type are well adapted for loads involving heavy starting torque and sudden overloads. They can be arranged for variable speed service by the insertion of a rheostat in series between the energy brushes.

Speed Control of A.C. Motors

Among the various methods developed for the speed control of a.c. motors, the following are of importance: 1, Adjustment of the resistance of the secondary circuit. 2, Adjustment of the primary voltage. 3, Using two motor primaries, one of which is capable of being rotated. 4, Changing the number of motor poles. 5, Operating two or more motors connected in cascade. 6, Adjusting the frequency of the primary current. 7,

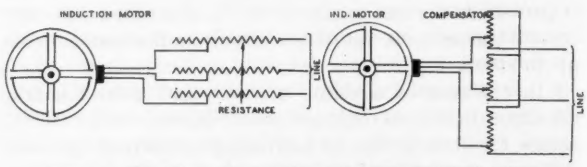


FIG. 4. PRIMARY METHOD OF SPEED CONTROL

Changing the number of phases of the secondary winding.

With secondary resistance speed control, the rotor (of a polyphase induction motor) usually has a Y connected winding to which is connected in each phase an external resistance as shown in Fig. 3. This method of control is very useful where constant speeds are not essential, for example in operating cranes, hoists and elevators and also for service in which the torque remains constant at each speed, as in driving fans, blowers and centrifugal pumps. On account of the energy loss in the resistors, the efficiency is reduced when operating at reduced speeds, this reduction being greatest at the slowest speeds. This method of control, in general is preferable to the primary control method shown in Fig. 4.

This method, it will be noted, makes use of either resistors or inductances in the primary circuit. It has

the disadvantage of poor speed regulation, low efficiency and is not in general commercial use. Squirrel cage motors, however, almost invariably make use of this arrangement for starting.

In the double primary arrangement, the motor (resembling an ordinary squirrel cage motor) has the primary divided vertically into halves, each with separate core and windings. One half can be rotated around the rotor by means of a worm-screw and rack device. When the two halves of the primary are placed so that like poles are in line, the rotor windings are subjected to maximum magnetic flux from the primary and the rotor will run at maximum speed. By turning the movable half of the primary, the flux acting on each rotor bar is gradually reduced, causing a reduction of the motor speed.

Since the synchronous speed of a polyphase motor is inversely proportional to the number of its poles, it is evident that a certain definite number of speeds could be obtained by varying the number of poles. Thus, on a 60-cycle circuit, a two-pole motor has a speed of 3600

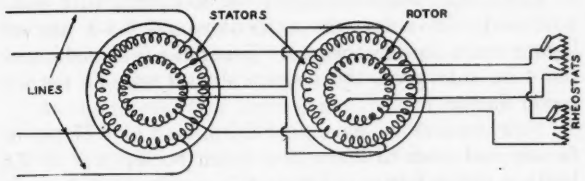


FIG. 5. TWO POLYPHASE MOTORS CONNECTED IN CASCADE

r.p.m., a four-pole motor, 1800 r.p.m., an eight-pole motor 900 r.p.m.

In practice, this is accomplished by using either two or more primary windings, each having a different number of poles or by using a single winding which can be connected so as to form different numbers of poles. These motors are made in a variety of sizes with two or four speeds. They are designed to give either constant horsepower or constant torque. The former is applicable to machine tools or similar drives where the load remains constant and the latter in operating fans, pumps, printing presses, etc., where the load is reduced as the speed decreases.

For many purposes, the scheme of using two or more motors connected in cascade offers a most convenient and economical method of speed control. All rotors are mounted on one shaft or several shafts may be rigidly connected. The primary of the first motor is connected to the line, its secondary to the primary of the second motor and so on. The secondary of the last motor can be either of the squirrel cage or of the phase wound type. In practice more than two motors are rarely used.

Since the synchronous speed of an induction motor is proportional to the frequency of the supply circuit, it is evident that the speed can be varied by changing the frequency of the supply circuit. This can be done where one motor is driven by one generator or by interposing a frequency changer between the motor and the line.

A final method of speed control is by changing the numbers of phases in the secondary winding but this method is inefficient and has no extensive commercial use. It is used only in experimental work.

Trouble in the operation of motors may be either of an internal or external nature. In many cases of reported trouble the voltage or the frequency is wrong. In the operation of induction motors, low voltage is a frequent cause of trouble. Naturally, in a case of motor trouble, tests should be made first of the circuit itself, to make certain that the voltage and frequency are correct. Polyphase circuits must be tested in all phases for it sometimes happens that a fuse on one phase will blow, causing an unbalanced condition.

When a new induction motor is received, it sometimes happens that in attempting to operate the machine, although it will start the currents are excessive and unbalanced and undue heating appears. If after examination nothing is found wrong with the air gap, belt tension, bearings, the probability is that the coils are wrongly connected or damaged.

If the motor is a three-phase machine, one coil of the rotor may be open circuited, the armature or rotor may have a defective winding just as may the field, or two coils or phases of the armature may be open circuited. Again, the armature may be connected properly but field coils or phases may be reversed, or parts of the field short circuited. One phase of the field may be open circuited.

In the case of synchronous motors, similar faults may occur but in addition faults must be looked for in the exciter.

Synchronous Condensers and Capacitors

Correction of Low Power Factor by Means of Synchronous or Static Condensers

A SYNCHRONOUS CONDENSER is a synchronous motor which is used only to correct power factor and does not pull any mechanical load.

By overexciting the fields, a synchronous condenser can be made to draw a current leading the pressure by nearly 90 deg. This current neutralizes an equal amount of lagging component. Since, as a rule, such machines are merely floated on the line and are not required to carry any mechanical load, they are not made as rugged as the usual synchronous motor. If necessary, however, they may simultaneously operate as motors and where this is the case it is customary to proportion them to operate to the extent of a consumption of 70 per cent of their rated kv-a. They can, when thus operating, be so excited that they also draw from the line, as leading wattless kv-a. 70 per cent of their rated capacity in kv-a., thus effecting power factor improvement at the same time that they are serving as motors to deliver mechanical energy.

Of course, low power factor on a system can also be corrected by means of static condensers or capacitors. These are used in the same way as synchronous condensers but only for power factor correction. The capacitor can be used to correct the low power factor of an entire system or, as is often the case, is used to correct the low power factor of a single motor and is mounted on the motor frame itself, or on a framework close to the motor. This latter type, known as the motor type of capacitor, is being used to an increasing extent.

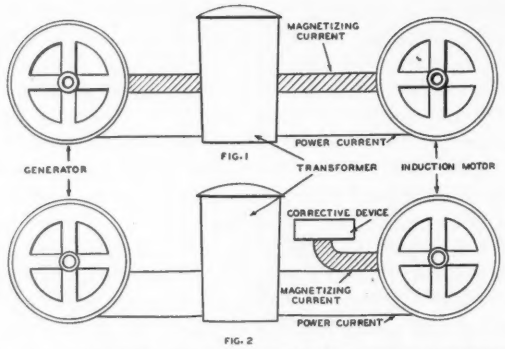


FIG. 1. GRAPHIC REPRESENTATION OF MAGNETIZING CURRENT AND POWER CURRENT
FIG. 2. HOW A CORRECTIVE DEVICE CONFINES THE MAGNETIZING CURRENT TO A SMALL PORTION OF THE CIRCUIT

The corrective device, either in the form of the synchronous motor, synchronous condenser or capacitor, relieves the generator of the task of supplying magnetizing current to the working parts of inductive apparatus. This magnetizing current, it must be understood, does no real work. The energy represented by this current is stored up in the form of a magnetic field in the inductive apparatus during one part of a cycle and is returned to the generator in a succeeding part of the cycle. This current, however, does heat the conductors through which it flows, hence, when the magnetizing current is large, the conductors will have to be larger. When no corrective device is present, this magnetizing current must be supplied by the generator, therefore, the conductors all the way from the generator to the inductive load, must be sufficiently large to carry both the power current and the magnetizing current.

Now, it is obvious that if the magnetizing current instead of being supplied by the generator can be supplied by some other device near the motor or inductive apparatus, the line conductors will be relieved of carrying this magnetizing current and can, therefore, be made smaller.

This is exactly what a synchronous condenser or capacitor does. In Fig. 1, we have an electrical system containing an induction motor. As shown, a large amount of current coming from the generator is magnetizing. In Fig. 2 is shown the same system with a corrective device added. Now, the magnetizing current is confined to a path between the corrective device and the motor. The advantages are obvious.

In order to solve industrial power factor problems rapidly and easily the General Electric Co. has devised a method whereby these problems can be solved by scale without resorting to degrees or functions of angles or square roots, "kw." or "kv-a." All that is needed is a scale, pencil and paper. A right-angle triangle with the sides in proportion 3 to 4 to 5 and a small T-square will save time and make the work more accurate. This method is as follows:

1. Draw horsepower as a horizontal line to a suitable scale as suggested by the following tabulation:

For 150 hp. or less	let $\frac{1}{16}$ in. =	2 hp.
Up to 500 hp.	let $\frac{1}{16}$ in. =	5 hp.
Up to 800 hp.	let $\frac{1}{16}$ in. =	10 hp.
Up to 2000 hp.	let $\frac{1}{16}$ in. =	25 hp.
Up to 8000 hp.	let $\frac{1}{16}$ in. =	100 hp.

2. Lines slanting upward to the right represent lagging power factor and their lengths are determined by dividing horsepower by lagging power factor.

3. Lines slanting downward to the right represent leading power factor and their lengths are determined by dividing horsepower by leading power factor.

4. Horsepower at unity power factor will be represented by horizontal.

Cut a right-angle triangle from cardboard with 3-in., 4-in. and 5-in. sides (the carpenters old 3-4-5 way of laying out a square corner). Using the 5-in. side over the 4-in. side gives the correct slant (rule 3) for 0.8 power factor.

Now suppose we have an 800-hp. load at 0.77 power factor, and wish to know how much horsepower in 0.8 leading power-factor synchronous motors must be substituted to raise the power factor to 0.9.

Solution: Use scale 1/16 in. = 10 hp. Draw 80/16 in. (5 in.) horizontal line A B, Fig. 3, and a vertical line at B. Divide 5 in. by 0.77 = 6½ in. In the vertical line, determine a point C, 6½ in. from A, and connect C with A. Divide 5 in. by 0.9 = 5 9/16 in. Determine a point D on the vertical line 5 9/16 in. from A and connect D with A. Apply the 0.8 leading power factor slant of the triangle at D and draw D E. Measure the horizontal distance E F = 17/16 in. or 170 hp. This is our answer.

Suppose, however, that in a certain factory with an 800-hp. load, the power factor is 0.77. What size synchronous condenser will be required to raise the power factor to 0.9?

As in the first problem, draw the base, perpendicular and the two lagging power factor slants. (See Fig. 4.) Measure C D 27/16 in. = 270 hp. Multiply by 0.89* = 240 kv-a., answer.

These two examples will serve to indicate the general procedure involved. Other conditions can be solved in a similar manner.

*Assumed motor efficiency, 84 per cent, i.e., 0.746/0.84 = 0.89.

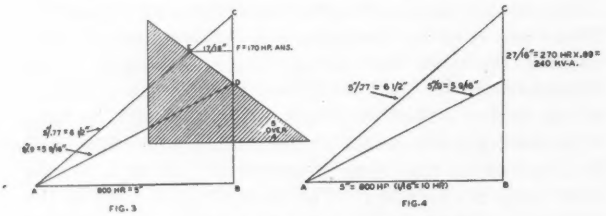


FIG. 3. SOLUTION TO PROBLEM 1
FIG. 4. SOLUTION TO PROBLEM 2

EVEN THE BEST paint cannot be expected to give good service if it is not properly applied. Failure to prepare the surface properly for painting is a frequent cause of short life. Painting over loosely adhering mill scale, rust, blisters, grease or wet spots comes in this classification. Improper application of the paint such as failure to stir to a uniform consistency or to apply a good even, well brushed coating is another frequent trouble and still a third is the application of a good grade of paint to a service for which it is not intended.

Adequate Lighting Increases Production

FUNDAMENTALS OF ARTIFICIAL ILLUMINATION PRACTICE DICTATE SUITABLE QUALITY, PROPER DIRECTION AND CORRECT AMOUNT OF LIGHT. LIGHTING STANDARDS STEADILY IMPROVING

LIGHTING STANDARDS are gradually creeping to a higher level as the importance of proper illumination is demonstrated. Comfort, safety and economical production are all factors in determining the correct amount of light and in as much as the effect of lighting on factory production is the easiest to measure as well as the most convincing argument, Fig. 1 is shown to indicate the value of improved lighting standards. This chart was drawn from test data collected in the inspection department of a large industrial concern.

The fundamental unit of intensity of light is the foot-candle. This is the intensity of light which falls on a surface 1 ft. from a standard candle. The dimensions of this standard candle are fixed by agreement, as are other fundamental units, but it is seldom used in practice because of the greater convenience of other secondary filament lamp standards.

As the intensity of light is not the same in all directions, different definitions are necessary to define the direction in which the intensity is measured. Horizontal candlepower, mean horizontal candlepower and mean spherical candlepower definitions are illustrated by Fig. 2. Hemispherical candlepower is sometimes used in connection with street lighting where only the lower hemisphere is considered.

Distance is an important factor as the light intensity varies inversely as the square of the distance. With the candle S of Fig. 3, the intensity at A would be 1 foot candle, but at B 2 ft. from S it would be in the ratio of 1 to 2^2 or ¼ while at C, 3 ft. from S, it would be 1/9-foot candles. By definition, the amount of light falling on a surface of 1 sq. ft. illuminated to an intensity of 1-foot candle, is one lumen. Thus, in Fig. 3, if A were an area of $\frac{1}{16}$ sq. ft. (¼ × ¼) the amount of light falling on the spherical surface bounded by the four sides would be area × cp ($\frac{1}{16}$ × 1) or $\frac{1}{16}$ lumen. At B the candlepower is only ¼ and the area is increased to ¼ (½ × ½) so the amount of light falling on the area would be area × cp (¼ × ¼) or $\frac{1}{16}$ lumen. At C the intensity is 1/9 cp. and the area $\frac{9}{16}$ (¾ × ¾) so that (1/9 × $\frac{9}{16}$) or $\frac{1}{16}$ lumen would also fall on surface C.

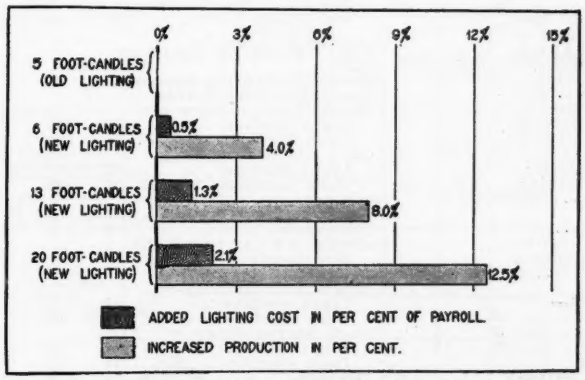


FIG. 1. INCREASED PRODUCTION FAR EXCEEDS THE COST OF ADDED LIGHTING

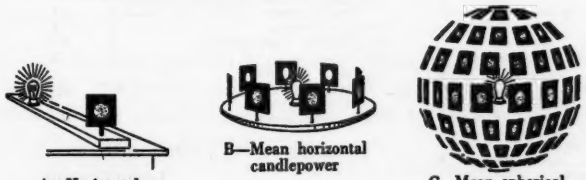


FIG. 2. MEASUREMENT OF CANDLEPOWER

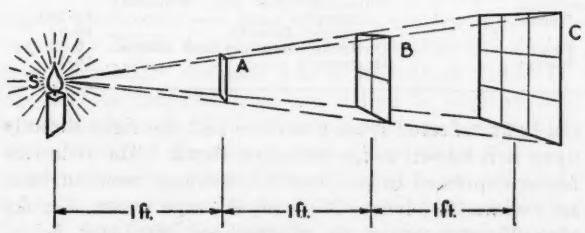


FIG. 3. ILLUMINATION VARIES INVERSELY AS THE SQUARE OF THE DISTANCE

TABLE I. SPACING OF OUTLETS FOR UNIFORM LIGHTING

Ceiling Height (Or Height in the Clear) (C)	Spacing Between Outlets		Spacing Between Outside Outlets and Wall		Approximate Area per Outlet (At Usual Spacing)
	Usual (D)	Maximum (For Units at Ceiling) (D)	Aisles or Storage Next to Wall (A)	Desks, Workbenches, etc., Against Wall (B)	
(Feet)	(Feet)	Not more than*		Not more than*	(Square Feet)
8	7	7½	Usually one-half actual spacing between units	3	50–60
9	8	8		3	60–70
10	9	9		3½	70–85
11	10	10½		3½	85–100
12	10–12	12		3½–4	100–150
13	10–12	13		3½–4½	100–150
14	10–13	15		4–5	100–170
15	10–13	17		4–5	100–170
16	10–13	19		4–6	100–170
18	10–20	21		4–6	100–400
20	18–24	24		5–7	300–500
22	20–25	27		5–7	400–600
24	20–30	30		6–8	400–900
26	25–30	33		8–9	600–900
30 and up	25–30	40		8–10	600–900

*Where it is definitely known that some form of indirect lighting will be used, the maximum spacing between outlets may be increased about two feet, and the distance from the outside outlets to the wall may be increased by one foot.

TABLE II. MOUNTING OF LIGHTING UNITS

DIRECT LIGHTING UNITS				SEMI-INDIRECT AND INDIRECT LIGHTING	
Actual Spacing Between Units (D)	Distance of Units from Floor Not Less Than (H)	Desirable Mounting Height in Industrial Interiors (R)	Desirable Mounting Height in Commercial Interiors (R)	Actual Spacing Between Units (D)	Recommended Suspension Length (Top of Bowl to Ceiling) (S)
(Feet)	(Feet)			(Feet)	(Feet)
7	8	12 feet above floor if possible—to avoid glare, and still be within reach from stepladder for cleaning.	The actual hanging height should be governed largely by general appearance, but particularly in offices and drafting rooms, the minimum values shown in Column H should not be violated.	7	1–3
8	8½			8	1–3
9	9			9	1–3
10	10			10	1½–3
11	10½			11	2–3
12	11			12	2–3
14	12½	Where units are to be mounted much more than 12 feet it is usually desirable to mount the units at ceiling or on roof trusses.		14	2½–4
16	14			16	3–4
18	15			18	3–4
20	16			20	4–5
22	18			22	4–5
24	20			24	4–6
26	21			26	4–6
28	22			28	5–7
30	24			30	5–7

This relation greatly simplifies the design of lighting installations for once the area and the lighting intensity in candlepower are known it is a simple matter to determine the lumens needed. If it is desired to illuminate 100 sq. ft. to an average of 10 cp., 1000 lumens must

Since the facility with which objects can be seen depends upon the amount of light they reflect, high levels of illumination must be provided when the materials are dark. This also applies to walls, as well as the materials which are being worked upon. The ratio between

TABLE III. PRESENT FOOT CANDLE STANDARDS

Commercial Interiors

	Foot-Candles Recommended Practice	Foot-Candles Recommended Minimum
Hospitals:		
Lobby and Reception Room	6	4
Corridors	3	2
Wards (with local illumination)	5	3
Private Rooms	8	5
Night illumination	0.2	0.1
Operating Table	100-200	75
Operating Room	15	10
Laboratories	15	10
Hotels:		
Lobby	8	5
Dining Room	6	4
Kitchen	10	6
Bed Rooms	8	5
Corridors	3	2
Writing Room	12	8
Office Buildings:		
Private and General Offices—Close Work	15	10
No Close Work	10	8
File Room	6	4
Vault	6	4
Reception Room	6	4
Railway:		
Depot-Waiting Room	8	5
Ticket Offices	12	8
Rest Room, Smoking Room	8	5
Baggage Checking Office	12	8
Storage	6	4
Concourse	6	4
Train Platform	4	2
Schools:		
Auditorium	8	5
Class Rooms, Library and Office	12	8
Corridors and Stairways	5	3
Drawing	25	15
Laboratories	12	8
Manual Training	12	8
Sewing Rooms	25	15
Study Room—Desks and Blackboards	12	8
Stores—Department and Large Specialty:		
Main Floors	15	10
Other Floors	12	8
Basement Store	15	10

Industrial Interiors

Aisles, Stairways, Passageways	3	2
Automobile Manufacturing:		
Automatic Screw Machines	15	10
Assembly Line	15	10
Frame Assembly	12	8
Tool Making	20	12
Body Manufacturing—Assembly, Finishing and inspecting	50-100	25
Chemical Works:		
Hand Furnaces, Boiling Tanks, Stationary or Gravity Crystallizing	5	3
Mechanical Furnaces, Generators and Stills, Mechanical Driers, Evaporators, Filtration, Mechanical Crystallizing Bleaching	6	4
Tanks for Cooking, Extractors, Nitrators, Electrolytic Cells	10	6
Clay Product and Cements:		
Grinding, Filter Presses, Kiln Rooms	5	3
Molding, Pressing, Cleaning and Trimming	8	5
Enameling	10	6
Color and Glazing	15	10
Coal Breaking and Washing, Screening	5	3
Construction—Indoor General	5	3
Elevator—Freight and Passenger	8	5
Forge Shops and Welding	10	6
Foundries:		
Charging Floor, Tumbling, Cleaning and Shaking Out	8	5
Rough Molding and Core Making	10	6
Fine Molding and Core Making	15	10
Glass Works:		
Mix and Furnace Rooms, Pressing and Lehr, Glass Blowing Machines	10	6
Grinding, Cutting Glass to Size, Silvering	12	8
Fine Grinding, Polishing, Beveling, Inspection, Etching and Decorating	15	10
Glass Cutting (Cut Glass) Inspecting Fine	25-50	15
Ice Making:		
Engine and Compressor Room	10	6
Laundries and Dry Cleaning	12	8
Locker Rooms	6	4
Machine Shops:		
Rough Bench and Machine Work	10	6
Medium Bench and Machine Work Ordinary, Automatic Machines, Rough grinding, Medium Buffing and Polishing	15	10
Fine Bench and Machine Work, Fine Automatic Machines, Medium Grinding, Fine Buffing and Polishing	20	12
Extra Fine Bench and Machine Work, Grinding (Fine Work)	50-100	25
Meat Packing:		
Slaughering	8	5
Cleaning, Cutting Cooking, Grinding, Canning, Packing	12	8
Offices:		
Private and General—Close Work	15	10
No Close Work	10	8
Drafting Room	25	15
Paper Manufacturing:		
Beaters, Machine, Grinding	6	4
Calendering	10	6
Finishing, Cutting and Trimming	12	8
Power Plants, Engine Rooms, Boilers:		
Boilers, Coal and Ash Handling, Storage Battery Rooms	8	3
Auxiliary Equipment, Oil Switches and Transformers	8	5
Switchboard, Engines, Generators, Blowers, Compressors	10	6
Store and Stock Rooms:		
Rough bulky material	3	2
Medium or fine material requiring care	8	5
Structural Steel Fabrication	10	6
Textile Mills:		
(Cottons)—Opening, and Lapping, Carding, Drawing-frame, Roving, Dyeing	8	..
Spooling, Spinning, Drawing-in, Warping, Weaving, Quilling, Inspecting, Knitting, Slashing (over beam end)	12	8
(Silk)—Winding, Throwing, Dyeing	12	8
Quilling, Warping, Weaving and Finishing—Light Goods	10	6
Dark Goods	20	15
(Woolen)—Carding, Picking, Washing and Combing	6	4
Twisting and Dyeing	10	..
Drawing-in, Warping—Light Goods	10	6
Dark Goods	15	10
Weaving—Light Goods	12	8
Dark Goods	20	12
Knitting Machines	15	10
Toilet and Wash Rooms	6	4
Upholstering:		
Automobile, Coach and Furniture	15	10
Warehouse	3	2
Woodworking:		
Rough Sawing and Bench Work	8	5
Sizing, Planing, Rough Sanding, Medium Machine and Bench Work, Gluing, Veneering, Cooperage	12	8
Fine Bench and Machine Working, Fine Sanding and Finish	15	..

Outdoor Lighting

Automobile Parking Spaces	1	0.5
Bulletin and Post Boards:		
Bright Surroundings—Light Surface	30	20
Dark Surface	50	30
Dark Surroundings—Light Surface	15	10
Dark Surface	30	20
Building:		
Construction Work	6	4
Excavation	2	1
Building Exteriors and Monuments — Floodlighted:		
Bright Surroundings—Light Surface	10	6
Dark Surface	20	15
Dark Surroundings—Light Surface	6	4
Dark Surface	12	8
Dredging	2	1
Flags—Floodlighted	25-50	15
Loading Docks	3	2
Piers:		
Freight (See Loading Docks)		
Passenger	4	2
Prison Yards	3	2
Protective Industrial	1	0.5
Quarries	3	2
Railway Yards		
General	0.25	0.15
Scale House	3	2
Storage Yards	1	0.5

Streets and Thoroughfares

	Lamp Lumens per Linear Foot of Street
Business District:	
White Way—Large City	500-2000
Small City	200-500
Park Boulevards	50-100
Thoroughfares and Wholesale Districts	50-200
Residence Streets	20-40
Outlying Districts and Alleys	5-10
Highways	10-20

be projected on the surface. The proportions of lumens generated by the lamp which reach the working surface is called the coefficient of utilization. This coefficient depends upon the diffusing and reflecting equipment, the color of the walls and the proportions of the room. Light emission of lamps also decreases with use.

the light reflected from a surface and the light directly upon it is known as the reflection factor. The reflection factor expressed in per cent for common room surfaces are: white, 80; ivory, 70; buff, 65, sage green, 40; sky blue, 35; olive green, 20; cardinal red, 20; black, 5.

In designing a lighting system, the wiring should be

TABLE IV. ROOM INDEX FOR NARROW AND AVERAGE ROOMS

For Indirect Lighting Use Ceiling Height		FEET						
		9 and 9½	10 to 11½	12 to 13½	14 to 16½	17 to 20	21 to 24	25 to 30
For Direct Lighting Use Mounting Height		FEET						
		7 and 7½	8 and 8½	9 and 9½	10 to 11½	12 to 13½	14 to 16½	17 to 20
Room Width (Feet)	Room Length (Feet)	ROOM INDEX						
9 (8½-9½)	8-10	1.0	0.8	0.6	0.6			
	10-14	1.0	0.8	0.8	0.6			
	14-20	1.2	1.0	0.8	0.6	0.6		
	20-30	1.2	1.2	1.0	0.8	0.6	0.6	
	30-42	1.5	1.2	1.0	0.8	0.6	0.6	0.6
	42-up	2.0	1.5	1.2	1.0	0.8	0.6	0.6
10 (9½-10½)	10-14	1.2	1.0	0.8	0.6	0.6		
	14-20	1.2	1.0	0.8	0.6	0.6	0.6	
	20-30	1.5	1.2	1.0	0.8	0.6	0.6	
	30-42	1.5	1.2	1.2	1.0	0.8	0.6	0.6
	42-60	2.0	1.5	1.2	1.0	0.8	0.6	0.6
	60-up	2.0	1.5	1.5	1.0	1.0	0.8	0.6
12 (11-12½)	10-14	1.2	1.0	0.8	0.8	0.6	0.6	
	14-20	1.5	1.2	1.0	0.8	0.6	0.6	
	20-30	1.5	1.2	1.2	1.0	0.8	0.6	0.6
	30-42	2.0	1.5	1.2	1.0	0.8	0.6	0.6
	42-60	2.0	1.5	1.5	1.2	1.0	0.8	0.6
	60-up	2.0	2.0	1.5	1.2	1.0	0.8	0.6
14 (13-15½)	14-20	1.5	1.2	1.0	1.0	0.8	0.6	0.6
	20-30	2.0	1.5	1.2	1.0	0.8	0.6	0.6
	30-42	2.0	1.5	1.5	1.2	1.0	0.8	0.6
	42-60	2.0	2.0	1.5	1.5	1.0	0.8	0.6
	60-90	2.5	2.0	2.0	1.5	1.2	1.0	0.6
	90-up	2.5	2.0	2.0	1.5	1.5	1.2	0.8
17 (16-18½)	14-20	2.0	1.5	1.2	1.0	0.8	0.6	0.6
	20-30	2.0	1.5	1.5	1.2	1.0	0.8	0.6
	30-42	2.5	2.0	1.5	1.2	1.0	1.0	0.6
	42-60	2.5	2.0	2.0	1.5	1.2	1.2	0.8
	60-110	2.5	2.0	2.0	1.5	1.2	1.2	0.8
	110-up	3.0	2.5	2.0	2.0	1.5	1.2	1.0
20 (19-21½)	20-30	2.5	2.0	1.5	1.2	1.0	0.8	0.6
	30-42	2.5	2.0	2.0	1.5	1.2	1.0	0.8
	42-60	2.5	2.5	2.0	2.0	1.5	1.2	0.8
	60-90	3.0	2.5	2.0	2.0	1.5	1.2	1.0
	90-140	3.0	2.5	2.5	2.0	1.5	1.5	1.0
	140-up	3.0	2.5	2.5	2.0	1.5	1.5	1.0

is satisfactory for small bays; in rectangular bays the interspaced system equivalent to 1½ outlets per bay can often be used; two units per bay is applicable where the width is less than two thirds the length; the staggered layout is also equivalent to two outlets per bay but gives a less favorable appearance; the four-two system where alternate bays have but two lights is equivalent to three units per bay; four units per bay is the most commonly used, however, for rooms or bays of usual dimensions.

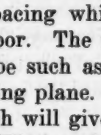
Having determined the probable spacing for uniform illumination from Tables I and II and the requirements of the construction plan, the lamp lumens can be calculated from the equation:

$$L = \frac{A \times Fc}{N \times U \times I} = \frac{a \times Fc}{U \times I}$$

Where:

L = lumens per outlet
A = floor area in square feet
a = floor area per outlet in square feet
N = Number of outlets
Fc = foot candles desired (from Table III)
U = Coefficient of utilization (from Table V)
I = probable average in per cent of initial illumination (from Table V)

TABLE V. CHARACTERISTIC PROPERTIES AND UTILIZATION FACTORS OF DIFFERENT TYPE REFLECTORS

LIGHTING UNIT		RELATIVE FOOT-CANDLES FOR A GIVEN LAMP SIZE		APPEARANCE OF LIGHTED ROOM	DIRECT GLARE	RE-FLECTED GLARE	SHADOWS	MAINTENANCE	PROBABLE AVERAGE ILLUMINATION—AS FRACTION OF INITIAL ILLUMINATION			CEILING	VERY LIGHT (70%)			FAIRLY LIGHT (50%)			FAIRLY DARK (30%)	
		On Horizontal	On Vertical						Clean Conditions	Average Conditions	Dirty Conditions	WALLS	FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY DARK (30%)	VERY DARK (10%)
												ROOM INDEX	COEFFICIENTS OF UTILIZATION							
15 Open Semi-Indirect Enameled Deflector Medium Density Glass Bottom Plate 90° to 180°—54% 0° to 90°—18%		B− Very Fair	C Fair	A Excellent	A− Very Good	B+ Very Good	A− Very Good	C Fair	.70	.60	...	0.6	.18	.15	.13	.15	.12	.10	.10	.08
												0.8	.22	.19	.17	.19	.16	.14	.13	.11
												1.0	.25	.22	.20	.21	.18	.16	.15	.13
												1.3	.28	.25	.22	.24	.21	.19	.16	.15
												1.5	.31	.27	.24	.26	.22	.21	.17	.16
												2.0	.34	.31	.28	.28	.25	.24	.20	.19
												2.5	.37	.34	.32	.30	.28	.26	.22	.21
												3.0	.39	.36	.34	.32	.29	.28	.23	.22
												4.0	.43	.40	.37	.34	.32	.31	.25	.24
												5.0	.44	.41	.40	.36	.34	.32	.26	.25
16 Enclosed Luminous Bowl Indirect 90° to 180°—64% 0° to 90°—6%		C+ Very Fair	C Fair	A Excellent	A+ Excellent	A+ Excellent	A Excellent	B− Very Fair	.75	.65	...	0.6	.14	.11	.10	.11	.09	.07	.06	.05
												0.8	.18	.14	.13	.14	.11	.10	.07	.06
												1.0	.20	.17	.15	.15	.13	.11	.09	.07
												1.3	.23	.20	.17	.18	.15	.13	.10	.09
												1.5	.26	.22	.19	.20	.17	.15	.11	.10
												2.0	.29	.26	.23	.22	.19	.17	.13	.12
												2.5	.31	.28	.26	.24	.21	.20	.14	.13
												3.0	.34	.31	.28	.25	.23	.21	.15	.14
												4.0	.37	.34	.32	.27	.26	.24	.17	.16
												5.0	.39	.36	.34	.30	.27	.26	.18	.17
1 RLM White Bowl Lamp 90° to 180°—0% 0° to 90°—66%		A Excellent	B Good	B Good	B+ Very Good	B Good	B+ Very Good	A− Very Good	.80	.75	.65	0.6	.32	.28	.25	.32	.28	.25	.27	.25
												0.8	.40	.36	.34	.39	.35	.33	.35	.33
												1.0	.43	.39	.37	.42	.39	.37	.39	.37
												1.3	.46	.43	.41	.45	.43	.41	.43	.41
												1.5	.48	.45	.43	.47	.45	.43	.45	.43
												2.0	.52	.50	.48	.51	.49	.47	.49	.47
												2.5	.56	.54	.52	.55	.53	.51	.53	.51
												3.0	.57	.55	.53	.56	.54	.52	.54	.52
												4.0	.60	.58	.56	.59	.57	.55	.57	.55
												5.0	.61	.59	.57	.60	.58	.57	.58	.56

given the most careful attention. Costs of changes in lighting are made up largely of wiring costs and it is desirable to provide wiring adequate to take care of future as well as present needs.

The number of outlets or lights is determined by the allowable spacing which is a function of their height above the floor. The relation between height and spacing should be such as to provide uniform illumination on the working plane. Spacing of outlets and mounting heights which will give good results are given in Tables I and II. When units are spaced less than the maximum permissible distance (A, B and D of Table I) they may be dropped from the ceiling to improve the appearance or to facilitate cleaning but in no case should they be dropped the distance below H of Table II.

Actual spacing of outlets will depend somewhat on building arrangements and columns. When the space is divided into bays by columns or ceiling beams some symmetrical arrangement is usually desirable. One unit

Foot candles recommended for different services are shown by Table III. These standards are being gradually raised and it is better to be too high than too low. In general, large rooms use light more efficiently than small ones and a room index has been determined to take care of this difference. A room in the shape of a

TABLE VI. LUMEN OUTPUT OF MULTIPLE MAZDA LAMPS

110-115-120 Volt Standard Lighting Service Clear Lamps		110-115-120 Volt Standard Lighting Service Mazda Daylight Lamps		220-230-240-250 Volt Service Clear Lamps	
Size of Lamp in Watts	Lumen Output	Size of Lamp in Watts	Lumen Output	Size of Lamp in Watts	Lumen Output
100	1350	100	900	100	1040
150	2300	150	1500	..	....
200	3200	200	2100	200	2700
300	5300	300	3500	300	4300
500	9500	500	6200	500	8100
750	14800	....	.....	750	13000
1000	21000	....	....	1000	18200
1500	33000	....	.....	1500	27300

TABLE VII. WIRE SIZE REQUIRED (WIRE LENGTHS IS DOUBLE THE LENGTH OF RUN)

WATTS PER CIRCUIT

LENGTH OF RUN (PANEL BOX TO OUTLET)	100	150	200	300	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200
30	14	14	14	14	14	14	14	14	14	14	14	14	14	12	12	12	12	10	10	10	10	10
40	14	The difference in the cost of wiring with No. 12 instead of No. 14 is so slight, and the advantages generally sufficient, that many electrical men specify No. 12 as the minimum size for branch circuits.						14	14	14	14	12	12	12	10	10	10	10	8	8	8	8
50	14							14	14	12	12	12	12	10	10	10	10	8	8	8	8	8
60	14							14	12	12	12	10	10	10	8	8	8	8	8	8	6	6
70	14	14	14	14	14	14	12	12	12	12	10	10	8	8	8	8	6	6	6	6	6	6
80	14	14	14	14	14	12	12	12	10	10	10	8	8	8	8	6	6	6	6	6	6	6
90	14	14	14	14	12	12	12	10	10	10	8	8	8	6	6	6	6	6	6	6	6	4
100	14	14	14	14	12	12	12	10	10	8	8	8	6	6	6	6	6	6	6	4	4	4
110	14	14	14	14	12	12	10	10	10	8	8	6	6	6	6	6	4	4	4	4	4	4
120	14	14	14	12	12	10	10	10	8	8	6	6	6	6	6	4	4	4	4	4	4	4
130	14	14	14	12	12	10	10	8	8	8	6	6	6	6	6	4	4	4	4	4	4	4
140	14	14	14	12	12	10	10	8	8	8	6	6	6	6	6	4	4	4	4	4	4	4
150	14	14	14	12	12	10	10	8	8	8	6	6	6	6	4	4	4	4	4	4	4	2
160	14	14	14	12	12	10	10	8	8	8	6	6	6	4	4	4	4	4	4	4	2	2
170	14	14	14	12	12	10	10	8	8	8	6	6	6	4	4	4	4	4	4	4	2	2
180	14	14	14	12	10	10	10	8	8	8	6	6	6	4	4	4	4	4	4	4	2	2
190	14	14	14	12	10	10	8	8	8	6	6	6	6	4	4	4	4	4	4	4	2	2
200	14	14	14	12	10	10	8	8	8	6	6	6	6	4	4	4	4	4	4	4	2	2
210	14	14	14	12	10	10	8	8	8	6	6	6	6	4	4	4	4	4	4	4	2	2
220	14	14	14	12	10	10	8	8	8	6	6	6	6	4	4	4	4	4	4	4	2	2
230	14	14	12	12	10	8	8	8	6	6	6	6	4	4	4	4	4	4	4	4	2	1
240	14	14	12	10	10	8	8	8	6	6	6	4	4	4	4	4	4	4	4	4	1	1
250	14	14	12	10	10	8	8	8	6	6	6	4	4	4	4	2	2	2	2	2	1	1

This table shows the wire size required for 115-volt circuits of various lengths of run, based on a drop of two volts between the panel board and the outlets. It is difficult in branch circuits, at least with present wiring methods, to use larger than No. 8 wire because of the difficulty of handling in conduit. Where the proper wire size for a proposed installation, according to this table, is larger than No. 8, it is usually best either to provide more circuits with less load, or to relocate distribution centers to decrease lengths of run. The dotted line shows the usual practical limits for circuit load and length of run.

Note—These recommendations on wiring are based on the allowances of The National Code: i. e. circuits equipped with medium screw sockets limited to 15 amperes and not more than 12 outlets per circuit; mogul sockets—limited to 40 amperes and 8 outlets per circuit. Present wiring practice is usually well within the limit allowed by the code. In some cases it is necessary to meet other requirements of local codes.

10-ft. cube has a room index of 1, other values for narrow and average rooms are given in Table IV. The room factor affects the coefficient of utilization (as shown by Table V) as does the type of reflector and lighting arrangement used. Tabulated data showing the characteristics of several reflectors and their coefficients are given in Table V. The probable average illumination is also given in this table.

After substituting the necessary values in the equation and calculating the lumens required per outlet, the voltage of the lamps required can be had from Table VI.

TABLE VIII. RECOMMENDED MINIMUM CAPACITY TO TAKE CARE OF FUTURE NEEDS

Actual Floor Area per Outlet	CLASS A INSTALLATIONS (Such as Offices, Drafting Rooms, Factories, etc.)	CLASS B INSTALLATIONS (Such as Stores, School Rooms)	CLASS C INSTALLATIONS (Such as Neighborhood Stores, Storage Areas in Factories* and Basements)	CLASS D INSTALLATIONS (Such as Storage Areas in Garages and Unimportant Basements)
Square Feet	Wattage Capacity per Outlet	Wattage Capacity per Outlet	Wattage Capacity per Outlet	Wattage Capacity per Outlet
65–75	300	200	150	100
75–85	300	250	150	100
85–95	350	250	200	100
95–110	400	300	200	100
110–125	450	350	250	150
125–140	500	400	250	150
140–160	600	450	300	150
160–190	700	500	350	200
190–220	800	600	400	200
220–260	950	700	450	250
260–300	1100	800	550	300
300–340	1250	950	650	300
340–390	1450	1100	750	350
390–440	1650	1250	850	400
440–500	....	1400	950	450
500–560	....	1600	1050	500
560–630	....	1800	1200	550
630–710	....	....	1350	650
710–800	....	....	1500	750
800–900	....	....	1700	850

* In factories it is often desirable to convert storage areas into work places to meet immediate production needs. For this reason, it is recommended that storage areas be wired according to Class B specifications.

Wire sizes required to meet these voltage demands with a voltage drop not to exceed 2 v. are given in Table VII. Various codes, which must be adhered to, merely specify sizes in regard to safety requisites and do not consider the economy of operation.

In order that higher wattage lamps may be used in the outlets at a later date without rearranging circuits, the capacity per outlet should not be lower than given in Table VIII. The number of outlets per circuit should be as follows: outlets 300 w. or less not more than eight per circuit; outlets 300 to 750 w. not more than four per circuit; outlets 800 w. or over, not more than two per circuit.

This method of design is known as the lumen method and the data and methods were developed by the engineers at Nela Park. The data applies primarily to interiors where standard types of reflecting equipment are used to obtain general lighting of a substantially uniform level.

Application of Electric Heat in Industry

ECONOMY, PRINCIPLES INVOLVED, ELECTRIC FURNACE CONSIDERATIONS

ELECTRIC HEAT IS BEING used to an increasing extent in all branches of industry where the application of heat is a necessary operation in the manufacture of products. This is quite natural, for the use of electric heat presents many advantages. It definitely removes all limitations due to the presence of combustion at the point where the heat is desired and this is a great advantage, for the presence of combustion is detrimental rather than helpful in practically all of the innumerable heating applications in industry and in the home. When treated with electric heat, gears are likely to be stronger, bath tubs smoother and lenses clearer; bottles are less likely to break when annealed in electric furnaces, copper wire is more ductile and sheet brass is more uniformly free from scale.

Another factor which makes electric heat extremely desirable is that of ease of control. Electric heating permits of the development of heat at any temperature required or best suited to the work from the lowest temperature encountered to 2000 deg. F. for heaters employing metallic resistors and to much higher temperatures for heaters employing non-metallic resistors, or the electric arc.

There are some industrial processes in which fuel heat may be utilized to the best advantage, but the technical and commercial superiority of electric heat is so obvious, that it is gaining favor rapidly in all branches of industry.

The characteristics which distinguish electric heat from all other methods of heating and from which all its advantages arise are that the heat may be developed, 1, at a location remote from the point at which combustion takes place; 2, at any desired temperature best suited to the work; 3, at a high efficiency or economy of heat units and 4, at a high degree of concentration.

Electric heat may be utilized to advantage where the following considerations are involved:

1. Where the cost of electrical energy is less than the cost of fuel, due to the greater efficiency of application of the electric heater. This usually is the case with soldering tools, glue pots, chocolate warmers, plate warmers, etc.

2. Where other items of cost such as labor of attendance, investment charges, decreased waste or spoilage make the overall cost of the operation less. This usually holds for Japanning ovens, linotype pots, metal melting and heating furnaces.

3. When the increased rate of production makes the cost per unit of production less. Core ovens, bread ovens, heating pipe lines, soldering tools.

4. Where the improvement in quality of the product warrants the increase in cost. Japanning ovens, embossing presses, impregnating tanks, moulding presses.

5. Where sufficient collateral advantages are realized such as decreased fire hazard, greater safety, improved working conditions. Celluloid heaters, paper embossing, glue pots, soldering irons, sterilizers, water heaters, blueprint driers.

6. Where electric heating is so peculiarly well suited to the work, that comparison of costs need not be considered or where the use of fuel is inappropriate, impracticable or impossible. Under this rule come incubating rooms, crane cabs, drying electrical machinery.

Principles Involved in Electric Heating

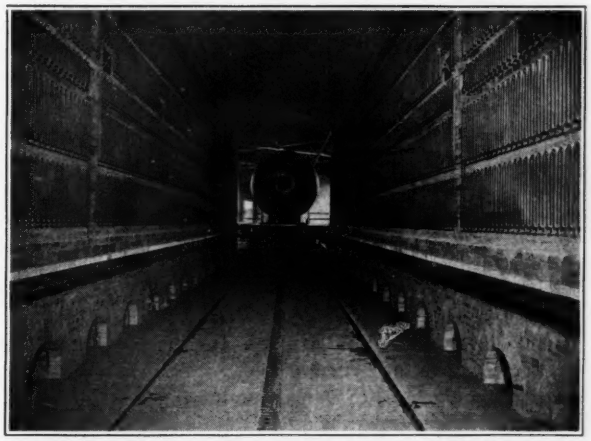
Electric heating is peculiar in that the efficiency of translation of electrical energy into heat is 100 per cent. When a kilowatt-hour of electricity is converted into heat, 3412 B.t.u. are released. This, however, does not imply that the efficiency of application is 100 per cent, but even in this respect it is usually much higher than the efficiency of application of heat from fuels. From this standpoint, it might seem that electric heat would always be more economical than heat from fuel, but this is not true for we must take into consideration the efficiency of producing the electricity, which produces the heat. Where electricity is derived from hydraulic power and where there is an abundance of it, and where the cost of fuel is relatively high, electric heat will be the most economical form of heat available but where the electricity is derived from the combustion of fuel, it is not necessarily economical. For at best we can only attain an efficiency of from 20 to 25 per cent in the conversion of the energy in fuel into electrical energy. So in any consideration of electric heat, where cost is of consequence, the efficiency of the production of electricity must be considered.

The transfer of heat from a hot body to a cold is accomplished either by radiation or by convection or both, and in the application of electric heat both of these are used. In such devices as soldering irons, glue pots, vulcanizing devices, the heat is transmitted by convection or conduction, while in most electric furnaces, ovens, toasters, glow lamp radiators, etc., the transmission is mostly by radiation. In the application of electric heat, the principles which underlie these two forms of heat transfer must be definitely understood.

Radiant heat raises the temperature only of a body which is opaque to heat waves; it passes through air without heating it in the slightest, and causes a rise of temperature in the air only by heating any objects that offer opposition to its passage through them, these in turn heating the air in contact with them by conduction. Heat waves, like light waves, are unaffected by air currents and the glow lamp radiator is, therefore, suitable for warming oneself by out of doors, or for quickly warming any portion of one's body.

When radiant heat meets a body that is opaque to it, it is partially absorbed by the opaque body and the absorbed radiation appears as heat upon the surface of the body. The rate of radiation is proportional to $T^4 - t^4$ (Stefan-Boltzman Law) where T is the absolute temperature of the sending surface and t is the absolute temperature of the receiving surface.

Since the radiation increases as the fourth power of the absolute temperature, it becomes relatively enormous at high temperatures, and permits extremely high ratings in watts per sq. in. of radiating surfaces for such constructions as bare nickel-chromium resistors operating at 1000 to 2000 deg. F. and radiating directly from the resistor surface. Such heaters are, therefore, termed radiant heaters.



THE LARGEST AUTOMATICALLY CONTROLLED ELECTRIC FURNACE IN THE WORLD. AN UNMUFFLED ANNEALING FURNACE AT THE A. O. SMITH CORP., MILWAUKEE, WIS.

Methods of Producing Electric Heat

Electric heat may be developed in a large variety of ways, but all methods may be grouped into one of three classes, i.e., I, resistance heating; II, arc heating and III, high frequency heating. Although arc heating and high frequency heating are for convenience grouped separately, they, like the first, depend upon resistance for the production of heat. In the arc, air, gases and vapor through which the current has to pass to complete the circuit provide the resistor medium necessary to maintain the arc and convert the electrical energy into radiant heat. In high frequency heating, the conducting crucible or charge forms the resistor which converts the currents induced by an alternating electromagnetic field into heat energy.

Plain resistance heating may be accomplished either by using the substance heated as the resistor itself or it may be done by means of auxiliary elements acting as resistors. Where the substance heated functions as the resistor, we may use solid or liquid substances as the resistors. In the first case (solid) we have metal rods,

rivets (rivet heating and resistance butt welding) metal rings (induction-ring heating) sheet metal resistors (spot and seam welding) and graphite resistors (as in furnaces producing graphite electrodes).

Under liquid substances as resistors are listed: a, water resistors, as in instantaneous water heating; b, molten metal resistors, as in induction metal furnaces; and c, fused electrolyte resistors, as in aluminum furnaces.

When auxiliary elements are used to act as resistors, there are three main classes available as follows: 1, metallic wire or ribbon resistors (usually nickel-chromium alloys); 2, cast metallic resistors (nickel chromium or iron alloys) and 3, non-metallic resistors. Under the latter head come silicon carbide compounds in the form of rods and tubes, granular carbon resistors, carbon plate resistors under pressure and carbon core resistors surrounded by the charge, as in the carborundum furnace.

Arc heating may be divided into two general methods, first the direct arc method and second, the indirect method. In the direct method the arc may be either between the substances requiring heat or between the substances requiring heat and the electrode. Examples of the first class are flash welding and metal-electrode welding and of the second, carbon arc welding and iron and steel melting. With the indirect arc method, the substance is heated indirectly from an arc between two electrodes placed end to end or mounted at an angle to each other.

In the case of the high frequency method, heat is generated by induction of high frequency current in either a conducting crucible (with a non-conducting or conducting charge), in a semi-conducting crucible (with a conducting charge) or in a conducting charge in a non-conducting crucible.

Heating by Radiation

As stated previously, there are two ways in which the heat produced in an electric heating element may be transferred to the substance to be heated, first by radiation and second, by convection or conduction. Convection or conduction heating is employed mostly in plain resistance heating where the substance heated functions as the conductor, in the case of non-metallic auxiliary resistors and in high frequency heating. Radiation heating is used in the case of metallic auxiliary resistors and in electric arc heating.

In the radiation type furnace, the heat may be transmitted to the charge directly with no solid substance between the heating element and the charge or through a wall or muffle of fire clay or other refractory. These are called unmuffled and muffled electric furnaces, respectively. The primary object of the muffle in the case of the electric furnace is to protect the heating elements from injury or from the atmosphere. For this reason it is undesirable to use the muffle type furnace where the protection is not needed. In certain cases, however, furnace gases attack the nickel-chromium alloys, and under these conditions muffles are desirable.

The transfer of heat in both muffled and unmuffled types of electric furnaces is almost entirely by radiation. The circulation of the furnace atmosphere is created only by the differences in temperature within the chamber and as these differences are slight, the amount of heat transferred by convection is small.

In the radiant type furnace, the nickel-chromium resistors are usually mounted on suitable refractory supports protruding from the side walls of the furnace chambers. The resistors are spaced to allow from 1½ to 3 kw. per sq. ft. of side wall area. When bottom heat or additional capacity is required, it is customary to mount resistors horizontally on refractory supports beneath the hearth. Due to the muffling action of the hearth plates, the capacity of the bottom elements should be kept somewhat lower per square foot of area than the side wall elements.

Furthermore, the size and length of the bottom resistors should be increased to permit of their operation at lower watt densities than the side wall elements.

Factors Involved in Electric Furnace Design

In planning a suitable electric furnace, the following procedure will be found desirable:

1. Determine type of furnace heat suited to requirements.
2. Determine amount of material to be handled at each charge.
3. Determine minimum space required for a single charge and from this the approximate general dimensions of the furnace to handle it.
4. Determine the kilowatt capacity required for
   a. Absorption by (1) refractory linings, hearth, conveyor, etc., and (2) charge.
   b. Radiation from roof, walls and floor.
   c. Door and seal losses.
   d. Factor of safety.
5. Determine areas available for resistor mounting.
   a. $\frac{\text{Kw. estimated cap.}}{\text{Sq. ft. of wall space}} = \text{kw. per sq. ft.}$
   b. If kw. per sq. ft. is too great (over 3 kw.) it may be desirable to mount one third the capacity below the hearth plates, then
      $\frac{\text{⅔ estimated kw. cap}}{\text{sq. ft. wall space}} = \text{kw. per sq. ft. wall area.}$
   c. If kw. is still too great it will be necessary to increase chamber dimensions.
6. Calculate size and length of resistor to be used.
   a. Based on predetermined watt densities.
   b. Based on space available for mounting.

The absorption in (4) can be calculated by the formula

$$\text{Watt hours} = \text{specific heat} \times \text{lb.} \times \text{deg. F. temp. change} \div 3.412$$

These rules are presented, not with the idea that they will enable a novice to design an electric furnace, but merely to indicate some of the principles involved and to enable one to check the capacity of a given furnace. The design of an electric furnace should not be undertaken by a novice. Most electric furnace failures are directly traceable to poor design or misapplication. Slight errors in design, which might escape notice in fuel furnaces, often prove glaring faults in electric furnaces.

Application of Enclosed Electrical Resistors

HEATING COILS ENCASED IN METALLIC SHEATHS OF VARIOUS SHAPES HAVE MADE ELECTRIC HEATING ADAPTABLE TO A MULTITUDE OF INDUSTRIAL PROCESSES

DURING RECENT YEARS industry has made extensive use of heating elements that depend almost entirely upon convection and conduction to transmit heat to the material to be treated. These elements are well adapted to the heating of liquids or the melting of solids, having melting points at comparatively low temperature.

As a rule, these elements are made up of a coil of nickel chromium resistance wire, or other special material prepared by the manufacturer. This wire is wound around a core such as lava which is high in electrical resistance. Around the coil is some other insulating material such as asbestos, magnesium oxide powder, or

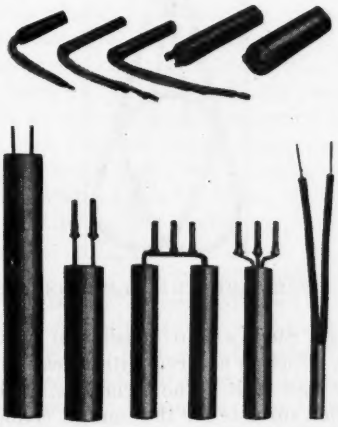


FIG. 1. TYPES OF CARTRIDGE HEATERS

in some cases where the element is flat, mica is used as the electrical insulator. This element is then enclosed in a metallic casing or tube, which is a good conductor of heat. Thus elements of this type can be made up into what is known as cartridge units which are rigid cylinders in shape; they can be built up into rigid copper-sheathed coils of any conceivable shape; they may be inserted in refractory material to give a flat heat plate; or they may even be properly formed and cast in iron.

One of the most common methods of heating liquids or melting low fusion point metals is by means of immersion plates which consist of an element imbedded in an iron casting provided with fins to aid heat radiation. These elements are so shaped as to fit into the containing vessels with the terminal poles well above the connection to the contributing electric system. Elements used in this way should be supplemented with some kind of heat controlling device which would prevent the liquid from becoming too hot.

Electric cartridge heaters are designed to supply concentrated heat over a small area where maximum operating does not exceed 800 deg. F. As a rule they are designed for direct contact with the material or object to be heated and must be applied only by fitting them in a hole drilled in a machine casting, so that the heat will be conducted away rapidly. Their temperature is usually so high that unless specially designed they are not suitable for operation in the air or for immersion in liquid. Their capacity ranges from 75 w. up to 600 w. for 110 v., the outside diameter ranging from 0.5 to 1.3 in. while the length varies from 3½ to 5¼ in.

HEATING TEMPERING BATHS

Another application of electric heat is in baths for oil or salt tempering. The bath may consist of a rec-

FIG. 2. IMMERSION TYPE HEATERS DESIGNED FOR HEATING LIQUIDS OR MELTING LOW FUSION POINT METALS

tangular sheet steel tank provided with a flange around the top and supported on angle-iron legs. The sides and bottom may be jacketed with 3 in. of heat insulating material in a sheet-metal casing. These baths are heated by immersion type units made up of helical, sheath-wire units cast into iron and placed in the bottom of the tank. The terminals are brought up the back of the tank and over the edge behind a protecting baffle. The units in

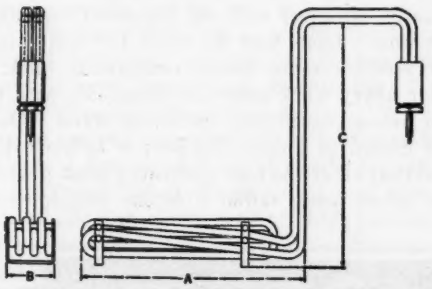


FIG. 3. HEATING ELEMENT USED IN TEMPERING BATH

the bottom are covered with a heavy wire mesh which protects them from mechanical injury and prevents small pieces of metal from falling in among the units. The wire mesh does not, however, prevent free circulation of oil. With this arrangement of heater, temperature can be maintained in the bath at a maximum of about 800 deg. F.

Another application of electrical heat in industry is for the melting of metals such as lead, copper, tin, solder and similar alloys at temperatures not to exceed 950 deg. F. For this purpose, metal-melting pots have been

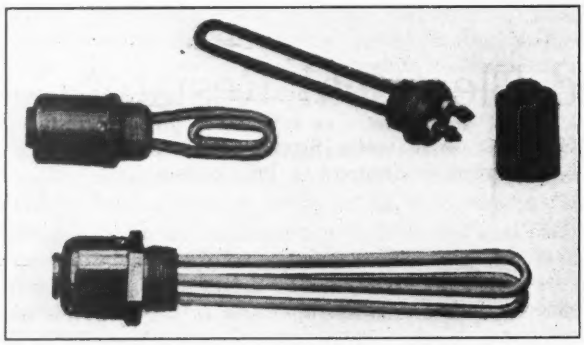


FIG. 4. FORMS OF IMMERSION COIL HEATERS FOR INSERTION IN SIDE OF KETTLES OR TANKS

designed in different sizes with approximate capacities ranging for lead, 40 to 1600 lb. These pots are designed for operation with either 110 or 220 v. a.c. or d.c. and consist of a durable, sheet-steel, cylindrical casing in which is supported a cast-iron crucible of the dimensions desired. The space between the casing and the crucible which measures about 3 in. is sufficiently insulated with a compact heat insulator. The heating units are of the cast-in, sheath-wire type, the number employed being dependent upon the capacity of the melting pot.

Electric heating has been applied successfully to glue pots and other containers where the temperature to be maintained is along the order of 140 to 150 deg. F. They may be constructed without a jacket or with a water jacket as desired. In the former case, the glue is heated by coming in direct contact with the walls of the glue pot and this unit is designed for continuous operation. With the water-jacketed type which is designed for intermittent service, there is interposed a heating medium of water between the electric heating elments and the glue container. Cartridge type heating units are used in both types of glue pots, thereby providing heating elements which are practically indestructible.

Among the small devices which are heated by electricity, mention should be made of soldering irons which are usually equipped with an improved cartridge type heating unit. Irons may be made for light and intermittent service or for heavy continuous work. Irons made for heavy work must not stand idle with the current on unless placed in a radiating stand. One thing in good design of a soldering iron is to have it so constructed that all of the heat generated must pass through the tip before being radiated to the atmosphere. This feature makes heating quick and reduces to a minimum the power loss.

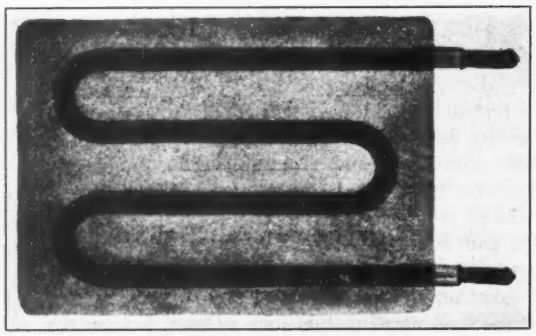


FIG. 6. X-RAY VIEW OF HOT PLATE SHOWING CAST-IN HEATING ELEMENT

Heaters of a helical immersion type are adapted for heating liquids in kettles, tanks, metal barrels, etc. For water heating, a copper-sheath unit of high heat intensity is used, but for heavier liquids, such as oil and paraffin, a heater having a much lower watt intensity must be used because of the fact that oils and similar liquids will not absorb heat as fast as water. Steel is used as the sheath material in oil-immersion heaters.

For control purposes, immersion heaters are built up with one to three units with proper switching equipment so that one or more of the elements can be turned on or off in order to maintain the proper temperature.

Installation of these immersion type electric heater units is made by drilling a hole in the tank, kettle or barrel to be heated and threading the hole for the standard type thread for which the element is threaded.

Lead sheathed immersion heaters are used in many cases where the solution to be heated will not attack the lead coating. Such a unit consists of a steel-sheathed helicoil unit which is covered with a lead jacket swaged tight to the steel unit. The terminals are brought into a terminal box suitable for the conduit connection.

FIG. 5. STEEL SHEATHED LEAD INCASED COIL

The uses for these electric units can be multiplied indefinitely to suit almost any heating problem which an industry presents. The construction of the unit, however, is quite similar to those already mentioned. Their economy in operation is due principally to the direct application of the heat at the point desired with heat loss held at a minimum and the exactness in temperature control which is possible.

THE AIR REFRIGERATING machine is simply a compressed air system in which the same supply of air in a closed circuit is used over and over again. It is first compressed and then cooled as low as the cooling water supply permits. It is then further cooled by expanding, the low temperature being attained by the withdrawal of energy in the form of work. In the usual vapor machine, the drop in temperature is attained by decreasing the pressure, that is, by throttling, so that the action of the two systems is fundamentally different although accomplished result is the same.

GEYSERS, volcanoes, wind, waves, tides and the sun have all been used as sources of power but the two commercial sources of energy which can be utilized for power purposes are the combustion of fuels and the falling of water.

The A. S. M. E. Fifty-First Annual Meeting

HUMAN PROBLEMS ALONG WITH MATERIAL HANDLING, HYDRAULICS, FUELS, AND CENTRAL STATION POWER OCCUPIED INTERESTS OF A.S.M.E. MEMBERS AT MEETING IN NEW YORK DECEMBER 1 TO 5

WITH A REGISTRATION of nearly 2600 at the Fifty-first Annual Meeting of the American Society of Mechanical Engineers, interest seemed to center around the unemployment situation throughout the country, economics as related to the engineering problems, and management which comes as part of the work of engineers. At a general conference on Monday, Colonel Arthur S. Woods, Chairman, The President's Committee for Employment, addressed the engineers on the present situation, solicited the aid of the engineers in stabilizing employment in the future. A symposium on industrial accident prevention was held under the auspices of the Standing Committee on safety, at which L. W. Wallace, Executive Secretary of the American Engineering Council, Lucian W. Chaney of the Bureau of Labor Statistics, and L. P. Alford, Vice-President of the Ronald Press Co., led the discussions with papers.

Again, on President's Night, Tuesday, December 2, a discussion took place on Engineering, Economics and the Problem of Social Well-Being in addresses by Ralph E. Flanders, Manager Jones & Lamson Machine Co., and Dr. Wesley C. Mitchell, Director of the National Bureau of Economic Research.

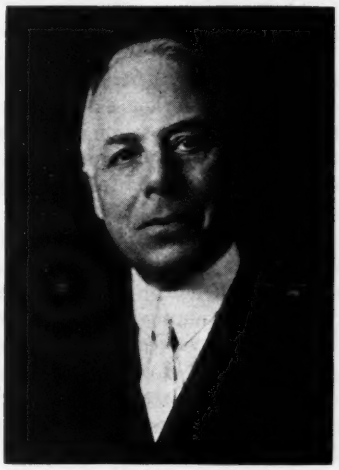
On Wednesday the problem of stabilization of employment in industry was discussed in an all day session, at which Edwin S. Smith, Director of Research for the Committee to Study Methods of Reducing Seasonal Business Slumps, Dr. Royal Meeker, Associate of Professor Irving Fisher, in Economics, New Haven, Connecticut, and Harvey C. Knowles, General Supt. Procter & Gamble Co., presented papers of extreme interest which aroused a great deal of discussion among those in attendance. At the Annual Dinner, Elliott Dunlap Smith, of Yale University, gave an address on Engineering Encounters with Human Nature. All of these discussions, together with the meetings on management, seemed to arouse among those in attendance a thought that the engineers should pay greater attention to this line of their work than they have in the past.

Technical problems of mechanical engineering were not neglected in the meeting as each of the various sections of the Society were given opportunity to present papers of timely interest. Among these were papers on lubrication engineering, applied mechanics, material handling, machine shop practice, railroading, hydraulics, industrial power, fuels, textiles, central station power, aeronautics, cutting metals, oil and gas power, boiler and furnace refractories, printing industries, properties of metals, mechanical springs and refrigeration.

Due to illness, it was impossible for President Charles Piez to attend any of the meetings, so the duties of officiating fell upon the vice-presidents.

The newly elected officers are: President, Roy V. Wright, managing editor of Railway Age. Vice-Presidents: William A. Hanley, director of engineering division of Eli Lilly & Co.; Thomas R. Weymouth, president of the Oklahoma Natural Gas Corp., and Dr. Harvey N. Davis, president of Stevens Institute of Technology. Managers: William L. Batt, president of the S K F Industries; Herbert L. Whittemore, chief of the engineering mechanics section of the U. S. Bureau of Standards; Harold L. Doolittle, chief designer of the Southern California Edison Co.

Aside from the technical meetings, two features of considerable interest were the art exhibit of the work of engineers, which included etchings, paintings and sculptures, and the exhibit of inventions of the late Elmer A. Sperry, which was shown in the Museum of the Peaceful Arts, and included Mr. Sperry's personal possessions, honors, decorations, medals, list of patents and various phases of his inventions.



ROY V. WRIGHT

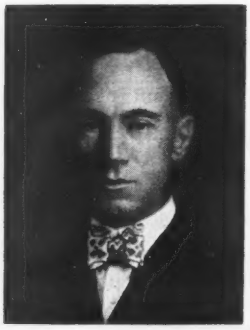
From among the numerous papers presented we have selected only a few which seem of particular interest to readers of Power Plant Engineering and give below short summaries and discussions of these papers reserving the publication of more complete abstracts for a later date.

Experiences with High Pressure

Operating experiences at Deepwater Station were described by K. M. Irwin, of the United Gas Improvement Corp. In presenting his paper Mr. Irwin gave a general description of the plant, details of which were published in a descriptive article in Power Plant Engineering of November 15, 1929, to which the reader is referred. The paper presented a history of the operation from the time the plant was first started in March, 1930, up until the present, summarizing the difficulties that have been encountered and segregating them among those that are directly chargeable to the pressure or temperature and

those which have been encountered due to other features of design.

He emphasized the fact that at the time this paper was prepared the plant had been in commercial operation only a little over three months and therefore had not had a long enough running period to give definite figures on economies obtained or on the operating efficiencies of the various parts of equipment.



WILLIAM A. HANLEY

THOMAS R. WEYMOUTH

Many of the fears of 1200 lb. have been centered around piping and the author stated that there have been no leaks on the larger sizes of high-pressure piping which is equipped with Sarlun joints. Some difficulties have been encountered with the smaller size pipe which has been used for drips and instrument connections. Most of this is chargeable to the use of composition gaskets, nearly all of which have been replaced by either soft steel or corrugated monel metal gaskets.

Difficulty was also encountered with leaks on the bonnets of some of the valves and again it was found due to the disintegration of composition gaskets which have been replaced. It was stated that economizers have been subjected to as high as 1800 lb. pressure and in general that these have been satisfactory, in that only one of the boilers has been troublesome with leaks, most of which have been due to the gaskets being improperly installed or the faces have not been properly prepared to receive the gaskets. Re-rolling of some of the boiler tubes has been necessary and this has usually stopped any leaks that have developed.

Other difficulties encountered in the boiler room which are entirely foreign to the pressure or temperature have been with the slag-tap furnace bottom, boiler side and rear walls and pulverized fuel systems. It is thought that bottoms of the type employed here can be operated without a great amount of trouble if the side walls are carefully watched for deflections. If the boilers are not taken off and on the line too frequently, operating periods of a year or more may be obtained without any serious maintenance work to the bottoms. Combinations of the particular ash of the fuel that is being burned with various compositions of refractory are being investigated in an attempt to obtain a refractory which is not so susceptible to slag erosion.

To date, it is impossible from the records to make any statement as to the relative efficiency of the bin versus the direct-fired system. No careful evaporating tests have been run, and from normal operating data it would appear that the systems were operating practically at the same furnace efficiency.

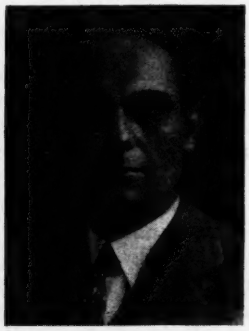
Difficulty has been experienced in the turbine room with silica scale deposited on the last rows of blading and in nozzles in the high pressure turbine which is used in the DuPont system. This difficulty has been entirely peculiar to this one machine out of the three high pressure machines, and to date no evidence of scale has been found in the other two high pressure units.

Summing up, the author stated that little difficulty has been experienced due to the pressure and temperature conditions selected for this plant and of the difficulties which have occurred the operators feel that they are well along on the road for remedies and corrections which it is hoped can be outlined in better detail in the near future.

In discussing this paper Grant Campbell described the level regulation in the evaporators which is employed at Deepwater.

James M. Taggart called attention to the fact that pumping hot water at or near the saturation point is a common source of trouble, and that to do so successfully the suction head must be sufficient to maintain the pressure above the flash point. He was also of the opinion that slag tapping furnaces are still somewhat in the experimental stage.

DR. HARVEY N. DAVIS



WILLIAM L. BATT

E. G. Bailey was of the opinion that relative merits of bin and direct fire systems are individual problems for each case.

Operation of Gilbert Station, formerly known as Holland Station, was the subject of a paper by E. M. Gilbert, president of W. S. Barstow & Co., Inc., who cited the fact that this station, being among the first class designed exclusively for high pressure steam, offered a good opportunity to study the experiences obtained during the first few months of operation. This plant, as he pointed out, was described in the March 1, 1929 issue of Power Plant Engineering, to which we would refer readers for details of equipment. Mr. Gilbert said that it is impossible at this time, due to the short period of operation, to report all operating problems as completely solved. Any operating difficulties which he cited should not be considered as a reflection on the effort or service of the manufacturers connected with the station. Where difficulties have been encountered the manufacturers have coöperated to the fullest extent and if a complete remedy of any trouble cannot be given it is due to lack of time.

He then went into detail experiences with piping, turbines, condensers, boiler feed, fourth stage drip pump, superheater, gas reheater, steam reheater, econo-

mizers, induced draft fan, burners, slag trouble, emergency boiler-feed pump, and feedwater, and gave operating results over the period from March 1 to August 30, 1930.

In discussing the paper, Shepard T. Powell stated that the troubles experienced with evaporators at Holland have probably been due to one or more of the following causes: 1, high water in evaporator shell; 2, rapid fluctuation of evaporator output, due to hand regulation; 3, high concentration in salines, in the evaporator shell; 4, clogging of veins in the vapor purifiers, and clogging of drip line from the vapor purifier section; 5, no baffle plate ahead of vapor purifier section.

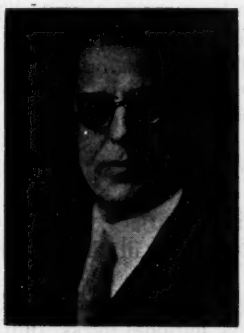
G. C. Derry called attention to improvements made in fan designs since the installation at Holland, particularly in the materials used to prevent erosion.

W. S. Johnston stated that he regards the regenerative cycle as permanent but the reheat cycle is felt to be transitory. It will not be necessary to resort to it when we can use higher initial steam temperature. He stated that superheater manufacturers are in position to supply equipment for 1350 lb. pressure and 1000 deg. F. temperature. He also stated that turbines can be built for 825 deg. F. temperature with proper arrangement of engine cylinders.

H. J. Kerr called attention to the fact that deposit on turbine blading is taking place with a steam which is purer than distilled water obtained in a drug-store. He still has hopes for further improvement in clean steam but the best possible water conditions should be maintained and a silica water should be avoided.

Power and Heat for Industrial Plants

One session of the Industrial Power Division of the Society was given over to the presentation and discussion of two papers which had been presented at the Second World Power Conference held in Berlin in June, 1930. One of these was entitled Engineering Aspects of Interchange of Power with Industrial Plants, by B. F. Wood of Allied Engineers, Inc., and the other on Combined Heat and Power Supply in Industrial Plants, by W. F. Ryan, of Stone & Webster Engineering Corp.



HERBERT L. WHITTEMORE

HAROLD L. DOOLITTLE

Mr. Wood stated that economical operation can be effected and overhead costs greatly reduced in a great many cases where public-utility or other steam-generating or hydro power plants find it possible to hook up with large industrial operations. The advent of high steam pressures has largely increased these possibilities and extended the engineering problems involved in their proper solution. The engineer must seek the maximum overall economy with minimum investment having regard for reliability of service, and then work out a plan for the undertaking that will be to the equal advantage of all parties at interest.

During recent years the great spread of interconnection which has taken place has resulted in benefits to the power systems in the following respects:

1. Greater leeway in the choice of plant sites.
2. Decrease in generating capacity due to diversity.
3. Decrease in spare generating capacity.
4. Increase in size of generating units, resulting in lower unit cost.
5. Staggering of new construction.
6. Making hydro capacity firm capacity.
7. Making possible the use of more economical units.

Among the means that may be employed to secure the advantages of massed resources of power production, with respect to utility and industrial plants, may be mentioned the following:

1. The interconnection of the electric circuits securing advantages of protection of service, diversity of load conditions, economy of operation, etc.

2. The establishment of jointly owned plants and facilities, supplying to the industrial plant electric, steam, or other power service, utilizing the utility system as the reservoir from which to draw or into which any and all surplus electric power may be poured.

3. The building and operation of plants and facilities by a utility company near the industrial plant, supplying such power service as required by the industrial plant, making up any deficiency from or taking any surplus electric power on the utility company's power system.

Readers are referred to the published abstract of Mr. Ryan's paper in the September 1 issue of Power Plant Engineering.

In the discussion which followed the presentation of these papers C. F. Hirshfeld stated that industrial competition is becoming more keen, both nationally and internationally, necessitating study of all means to reduce costs. Similar motives activate public utilities. The motives are driving toward a common solution, a solution along the lines indicated by Mr. Wood. The solution rests on diversity. Interconnection with industrials brings in a new set of diversities which can be used to the advantage of both the industrials and the customers of the utilities. It appears, therefore, as the next logical step in the steady march of ever-decreasing costs based upon the utilization of diversity. The course of the utility depends largely upon the stability of the industrial served.

J. H. Lawrence said in discussing Mr. Ryan's paper that it was regretted that executives have not had their organizations keep pace with developments in a subject which is absolutely essential to their companies. Power is one of these essentials. It is up to the engineering profession to educate the industrial executive in the economics of steam and power development. The industrial should not blindly follow central station design. Today the problem is attacked from the standpoint of building a plant which will be coördinated with manufacturing processes so far as heat and power are concerned.

Guy B. Randall was of the opinion that the great possibilities appear to lie in:

1. Joint ownership as quite clearly described in the two papers before us.
2. Simple interconnection of electric circuits.

Joint ownership may develop a fair field of action in some of the larger projects. A start has been made. But there are serious objections to it in the case of the majority of industrial companies unless the utilities use the new medium to insure the equivalent of far more favorable rates relatively than their present rate structures provide. In both Mr. Wood's and Mr. Ryan's papers, construction costs are given which for this discussion represent large power developments and the cost ranges from $100 to $114 per kilowatt. In my own recent experience a first class, 650-lb. industrial plant station ranging in capacity from 15,000 to 20,000 kilowatts can be built completely new for $70 to $80 per kilowatt, including all legitimate charges and profits.

It would appear that joint ownership and so-called mass production has yet to demonstrate that it may offer the public utility a suitable profit without serious infringement on the industrial plant potential profit. In competitive industries, profits cannot be standardized. But the high thermal efficiencies obtainable today in up-to-date plants of moderate cost open the door to attractive savings. Almost any plant is a good prospect. If it is a large buyer of power it may prove to be a better prospect.

Simple interconnection of electric circuits would seem to offer the really great and essential opportunity for development. Under this scheme, if the isolated plant has surplus power it dumps it into the general pool of power. If it needs some, it draws from the pool. There are no financial complications. But it must get paid reasonably for what it delivers and it must pay reasonably for what it gets.

Mr. Ryan questions industrial power costs of 1.5 mills per kilowatt hour including fixed charges. Out in Ohio that is easily possible if no reserve equipment is carried. With reserve equipment, a total cost of 2.0 to 3.0 mills including fixed charges is readily achieved provided only the load factor is good.

R. J. S. Pickett was of the opinion that the major obstacle to the more rapid development of interconnections by way of combination plants between public utilities and industrials is mainly lack of confidence of the two groups in each other. Comparative reliability seems to be the doubtful question. The dump power of industrials is another obstacle. Cost or interchange price was also mentioned as a point of controversy.

Edgar J. Kates stated as his observation that breakdown service loads apparently are not wanted by utility companies judging from the prohibitive rates frequently found. He cited one company's charges as $24 per year for each kilowatt of maximum demand contracted for under breakdown agreement. Such charges as these he thought warranted industrials in installing standby service equipment. In commenting on Mr. Ryan's paper, he asked why not design a combination power plant with steam and Diesel capacity carefully proportioned so that the load will be shared according to an analysis of capital investment as well as operating cost? Greater savings can be effected, he stated, by planning a well balanced combined plant in which both types of prime movers will be used more hours per year than a thermal analysis alone would call for.

E. D. Dickinson stated that manufacturers have anticipated the use of by-product power to its economical limit and have designed highly efficient back pressure and extraction turbines for by-product power application. The matter of bookkeeping is no doubt one of the most important and yet the most unreasonable elements tending to retard the by-product power situation.

Z. G. Deutsch stated as one of the difficulties often arising the amortization of present invested capital in power producing equipment.

J. M. Taggart cautioned that each case involved special engineering and a study of economic features in order to solve the problem effectively. Power supply companies tend to underestimate the value of a possible power supply from industrial plants and to disregard totally the value of an increase in capacity. Industrial concerns producing their own power, on the other hand, normally over-estimate their loads. Unprejudiced and accurate engineering is required to achieve a mutual profitable and efficient coöperation. He thought that many plants would be helped by proper scheduling throughout the factory of both heat and power loads.

Accomplishments of the Federal Power Commission

Federal Relations to Water-Power Development was the subject of the paper read by Frank P. Bonner, of the Federal Power Commission, in which he cited the work of the Federal Government in advancing the production and distribution of electric energy from water power sources. During the past decade the administration of the law regulating the utilization of power sites involving government interest has reposed with the Federal Power Commission. Although developments of many of the large rivers have been delayed by legislative embargoes and political controversies, the Commission has authorized the construction of many important projects, and about 2,600,000 hp. of capacity is now operating under license from the Commission. The proper division of authority between the government and the states has raised some complex problems which are pressing for solution.

He called attention to the fact that the U. S. Government is the largest real estate holder in the country. These holdings concentrated largely in the western states where vast areas of original public domain have been reserved for natural forests, national parks, Indian reservations and other purposes. He also outlined the federal jurisdiction over navigable streams, the purpose of the Federal Water-Power Act, cited the activities of the Federal Power Commission, and summarized the aggregate capacity of water-power plants under license.

In the discussion which followed presentation of this paper, it was pointed out that there are many small water-power sites in the East which are too expensive to develop under present federal control, where these plants must operate in competition with steam plants located directly in industrial centers. For this reason it was pointed out a more liberal interpretation by government authorities is needed to secure development of the third and fourth string plants. It was the belief of

some of those present that the Commission is looking after the interests of the people, yet abiding strictly by the law, under which the commission must operate and that the water-power companies should go along with the Commission and that probably a better understanding could be had between industrial men and the government by working through the American Engineering Council as an intermediary.

Consideration of Heat Transfer Calculations

When water screens were installed in pulverized fuel furnaces to prevent slagging of ash in the furnace bottoms tests were made to determine the rate of heat absorption in order to design properly the downcomers and risers, said William L. DeBaufre, of the International Combustion Engineering Corp., in his paper on Heat Absorption in Water-Cooled Furnaces. These tests generally consisted in isolating certain tubes and passing water through them at a sufficient velocity to give a moderate temperature rise.

In other cases the water screens were connected to steam drums separate from the main steam drums in the boiler so that the steam generated therein could be measured. The rate of heat absorption so determined per square foot of water-cooled surface exposed to radiation was compared with the operating capacity of the boiler in per cent of rating rather than attempting to connect the rate of heat absorption with the furnace temperature. This method of handling the problem was satisfactory as long as small portions only of the furnace walls were covered by water-cooled surfaces.

When larger portions of the refractory walls were replaced by water-cooled surfaces a relation between rate of heat absorption and furnace temperature was based on these data and on an experiment by John Bell made some years previously, in which one of the first row of boiler tubes was replaced by a similar tube through which water was circulated and the temperature rise noticed.

Based on the furnace heat balance an empirical "effectiveness factor" was derived by Mr. DeBaufre for water-cooled surfaces therein, relating the heat radiated by the burning fuel and products of combustion to the furnace outlet temperature. The value of this factor is calculated from certain experimental data for turbulent horizontally fired pulverized coal furnaces with bare water-cooled tube walls. For these experimental data, the fraction radiated of the heat liberated in the furnace was calculated and compared with the work of other authorities. The method of applying the effectiveness factor to designed problems was illustrated by showing the effect of preheated-air temperature upon the furnace outlet temperature.

Under the title Radiant Heat Transmission Between Surfaces Separated by Non-Absorbing Media, H. C. Hottel, of the Massachusetts Institute Technology, gave a dissertation on the fundamental laws of radiation from solids, including in the discussion the definition of normal intensities, Lambert's Cosine principle, relation between intensity and emissive power, the square-of-the-distance law, Kirchoff's law and the Stefan-Boltzmann law. Various surface arrangements were divided into two groups, one, in which one of the two surfaces is small relative to the distance separating them and, two, in which both surfaces are of considerable extent relative to their distance apart. Various cases of these and the effect of incomplete absorption were treated mathematically. The task of applying many of the equations given in the paper is simplified by presentation of numerous graphs.

Long Distance Gas Transmission

At the Oil and Gas Power session, George I. Rhodes, of Ford, Bacon & Davis, Inc., and Edgar G. Hill, of the same organization, presented a paper entitled Long Distance Transportation of Natural Gas, in which they stated that during the past 5 yr. progress in the art of long distance gas transmission had increased from pipe lines of 200 mi. in length to those 1000 mi. long. This progress has been economically possible in the transportation of large volumes of gas at high load factors largely as the result of pipes of greater strength and better quality than were formerly available. The higher pressure coming into use is of only indirect benefit through effective utilization of improved pipe. There has been no corresponding improvement in the compressing station necessary on long lines.

Large high-pressure lines are now commonly laid with extra long joints of pipe made by welding from shorter joints and coupled together with improved rubber packed couplings of the Dresser type.

Welded joints are now stronger, cheaper and more quickly made than formerly. Dresser type couplings are now made to design data secured from careful tests.

The authors stated that valves formerly used were not entirely satisfactory and higher pressure points to valves such as are used in superheated steam practice. Valves of restricted diameter are frequently used with Venturi nipples for connection into the lines of larger diameter. Further progress may result from further improvement in pipe, better methods of compression and other developments now only "idle dreams." As to the future, perhaps there will be better and stronger pipe so that the saving already made possible can be doubled. Perhaps the steam turbine driven centrifugal blower will be developed and save one-half of the cost of pumping the gas. Perhaps higher pressures and the resultant deviation from Boyle's Law will increase line capacity to an important extent, or some way may be found to change the gas into a non-condensible gas of several times the heat content with a higher gravity, which change would markedly reduce the cost of transportation. Perhaps some chemist will find the catalyzer that will liquefy the gas at a nominal cost, and re-gasify it at the market, thus saving one-half the cost of transportation. A supergas system may be achieved, interconnecting all the gas systems in America.

W. R. Kepler in discussing the paper showed that with a given pipe size the unit cost reduces as the pressure and necessary thickness increases. If, however, the diameter were increased and the pressure kept low, a lower unit cost could be obtained. For example, 175,000,000 cu. ft. would require a 24-in. pipe with 525 lb. operating pressure at a unit cost of $275 while a 28-in. or 30-in. pipe would require only 325 lb. or 275 lb. respectively at a unit cost of about $253.

Editorial Comment

Workers and Jobs

Unemployment, how much, why and its progress up and down ranks high as a topic for discussion this winter. It runs an even race with the same points as to business, Volstead law enforcement and pigmy golf. It would seem to deserve to head the list, as it is the problem of most vital interest to the greatest number of people. Numerous agencies are making surveys and investigations. Many people are making prophecies and expressing opinions. Movements are active to render first aid to the unemployed. But the Commission on Unemployment for the State of New York has submitted a report, showing careful analysis and making suggestions as to reduction of future unemployment which seems a real contribution toward a solution of the problem and deserves consideration.

Causes of unemployment are found to be: Seasonal activity to meet demand and conditions in industries; cycles of business activity and depression; displacement of workers by improvement in production methods; overmanning of industries to meet peak activities, resulting in lay offs during valleys in demand. Since these four causes differ in effect, evidently different remedies must be found, if possible.

Seasonal demand, as for summer and winter clothing can, in some cases, be met by manufacturing for stock or by stimulating dealers orders through off-season discounts. The problem is akin to improving the load factor in a power plant but is complicated by possibility of changes in styles, perishableness of product and carrying charges for expensive goods. Correlation of two or more lines of product, having intermeshing seasons and requiring similar manufacturing equipment is another solution. Much has been done along these two lines. A yearly sales budget with 1/12 the production assigned for each month is one method. Part time operation during dull seasons is really a plan for apportioning unemployment among many rather than letting it all fall on a less number but helps to maintain an organization and to minimize hardships. Any method of steadying production is obviously to the advantage of the manufacturer and the plant which furnishes power, as it allows of production of a given yearly output with lower overhead and plant charges.

When supply of perishable raw material is seasonal, as in canning, beet sugar making and the like, it would seem that little can be done to even up production. Movement of working forces from point to point as crops are ready is feasible but costly and unsatisfactory to the better class of workers. Work in such industries can, however, sometimes be intermeshed with that in factories whose peak comes at other than the crop season, to the benefit of both industries.

The Committee's conclusion is that good management can reduce, although not entirely do away with seasonal variation of employment and that it will pay manufacturers to steady operations as far as possible.

Since nobody has yet discovered quite what starts prosperity or depression and each depression is attributed to a different cause, the remedy for cyclical unemployment is not evident. Pushing public works and overhauling factory equipment during dull seasons are the methods so far suggested or applied and are now being used. Part time operation again serves to distribute the effects of dull times more evenly but is a palliative rather than a remedy. The working of several plans of unemployment insurance or assistance by private companies is discussed but the plans are too recent to show conclusive results as yet. Results of government unemployment payments and doles as attempted in European countries do not encourage the belief that they are the wise course. Some plan for insurance through private company or trade association activity, along lines similar to fire, accident and group life insurance would seem more likely to operate effectively and economically.

As the probability of abolishing seasonal and cyclic unemployment appears remote it would seem logical to establish a reservoir of funds to be filled and replenished during periods of activity and employment and which will supply the means of tiding over dull periods. To this reservoir, both workers and employers may well contribute, payment from it to be regarded the same as dividends paid from company reserves, not as charity. Details will vary but the principle would seem to be in accord with the self interest of business and industry as well as with the dictates of humanity.

Such a plan, combined with coöperating, well-conducted organizations for placing workers, the scheduling of steady production, so far as possible and definite utilization of public improvement work to dovetail with private work should help to lessen unemployment and to alleviate hardships which otherwise must follow unavoidable scarcity of jobs.

A New Principle in Power Plant Design

Design of power plants in such a way that each turbine generator was served by a group of boilers and auxiliaries, the whole operating as a distinct unit, has been carried out in the past in many important instances. Then, as all types of equipment were improved, as steam generating units and all their auxiliaries increased in reliability, the sizes and steaming capacities of those steam generating units could be increased. Improved methods of feedwater treatment reduced internal troubles, use of evaporated feedwater became more general and, as pressures and temperatures went up, the problem of embrittlement was encountered and solved. Firing methods and furnace construction, both in stoker-fired and pulverized coal-fired installations made rapid progress. Finally it seemed to some engineers that a plant could be designed in which one steam generating

unit could serve one electric generating unit, since one could operate as reliably and as long as the other.

This point was discussed at frequent intervals and finally three especially noteworthy plants appeared this year in which this fundamental principle of design is strikingly illustrated. One example was an industrial plant, the new installation of Champion Coated Paper Co. described in the December 1, 1930 issue of Power Plant Engineering. Here a three-element turbine generator is supplied with steam by a single boiler unit, stated to be the largest unit-fired pulverized coal burning unit yet built and the largest for high pressure. An old boiler plant is kept for emergency service.

Another outstanding example of the unit idea is found at South Amboy station, described in the July 15, 1930 issue of Power Plant Engineering. Here two vertical compound turbine generators are installed, with three boiler units. The design provides for serving each turbine by one boiler, with the third boiler at present forming spare capacity for the station. Space is provided, however, for a future third turbine unit, which will be served by the third boiler, thus carrying out the unit idea.

At South Amboy, another unusual illustration of the unit principle is found in the turbine generators. Each machine is of the vertical compound type, the high-pressure element mounted over the low-pressure element. The two elements are operated as a single unit, without provision for separate operation.

Heretofore, it has been the usual practice to design compound units so that the elements could operate separately in case of trouble. The inference to be drawn from the South Amboy turbine units is that the art of turbine design and operation has reached such a high degree of perfection that this precaution is no longer necessary. Operation of these South Amboy units to date indicates that such an inference is justified.

The third station that illustrates the unit principle in Bremo Bluff, soon to go into operation and designed by the same organization that designed South Amboy. Here two tandem-compound turbine generators are installed, each served by its single boiler unit and the necessary auxiliaries, with no spare boiler capacity installed. A brief preliminary description of this station was given in the June 15, 1930 issue of Power Plant Engineering.

These examples illustrate an important trend in power plant design. The demand in the utility industry for more system capacity per dollar of investment is insistent. The unit idea not only aids in meeting this demand but also simplifies many operating problems. It is significant, too, that one of the outstanding examples noted above is an industrial plant; it exemplifies the increasing interest of industrial executives in modern methods of power generation and the ability of industrial plant engineers to maintain a place in the front rank when they are given the necessary executive support. Adoption of the unit principle also shows that the manufacturers of power plant equipment are able to produce equipment of great reliability, as the plan could be carried out only as equipment of the highest reliability could be obtained for it. These three plants reflect the highest credit on their designers, on the makers of the equipment and on the owners.

Smoke Abatement and the Human Factor

In dealing with the smoke problem, the human factor looms large. The lethargy of the public is well known but, if facts can be presented regarding damage to property and health that intimately affect the individual, his coöperation is in a fair way to be secured.

A favorite political sport is to pass an ordinance in order to abate an evil. We smile at the expression "there ought to be a law" but there the matter usually rests. Twenty-four years ago a smoke ordinance was drafted for the city of Newark, N. J., which contained definite statements of what were violations, based upon the Ringelman chart, because the density method of violation determination is the only practical one. Preservation of health is of even greater importance than reduction of damage but no method of enforcing an ordinance based upon health considerations has yet been devised. The Newark ordinance also contained definite qualification requirements for the smoke inspector.

Inquiring why nothing was done, the public was told through the news columns that appointment of the smoke inspector had been illegal, because he did not meet the requirements laid down by the ordinance. The smoke inspector, backed by the politicians came back with the reply that the ordinance could not be understood by an ordinary person; it was too technical. Again through the news columns, the prediction was made that the politicians would take out the technical portion of the ordinance. This is exactly what happened.

Ordinances are necessary but with them is needed a group of public spirited men armed with red pepper squirt guns, who will keep on the job every minute.

Another feature in smoke campaigns is that well-meaning men and women, when they have been convinced that smoke is really destructive and can be abated, often advocate drastic legislation or impractical methods. About 5 yr. ago, in one of the sporadic attempts to secure free air unadulterated, the Women's Civic League of Baltimore endorsed the statement that New York City had the best smoke ordinance. This ordinance reads: "There shall be no smoke."

Decision of what should constitute a proper ordinance and the proper manner of administering a smoke abatement department should rest largely with engineers. Laymen can, however, do much good in arousing civic consciousness and a willing compliance with smoke regulation.

Acknowledgment

During the preparation of this Power Distribution and Utilization Number, considerable assistance was given by manufacturers in the field covered by the issue; authoritative works of reference, government bulletins, experiment station reports, society transactions and all other available sources of information were used extensively. In many cases, the source of information is given in the text but this arrangement could not be carried out completely and we wish in this way to acknowledge our indebtedness to those who have assisted and to thank them for their share in this issue.

Ninth Exposition of Power and Engineering

DISPLAY OF LARGE UNITS OF BOILER ROOM EQUIPMENT AND OPERATING EXHIBITS OF CONTROL EQUIPMENT, INSTRUMENTS, FULL SIZE EXAMPLES OF PIPING AND VALVES FOR HIGH TEMPERATURES AND PRESSURES, EPITOMIZE THE TRENDS OF THE YEAR

NINTH NATIONAL Exposition of Power and Mechanical Engineering, held at Grand Central Palace, New York City, December 1 to 6, 1930, was notable for its increased display of full size pieces of equipment of all types, most of them in actual operation as they would be in the power and industrial plant and for the attractive and artistic methods used to focus attention on this equipment. Over four hundred exhibitors displayed their products to the engineers who visited the Exposition in even greater throngs than those of last year. In addition to the apparatus of interest to engineers responsible for generation, distribution and utilization of electric power, steam, water, compressed air, oil, and so on, there were many exhibits of machine tools, products and methods of special interest to production engineers in industrial plants.

Examples of the full size commercial units exhibited in the combustion field were the two complete retorts of a 15 retort underfeed stoker about 26 ft. long, of a type used in several large central stations, and for smaller boilers other types of compact underfeed stokers and moving grate stokers.

Coal pulverizing equipment was represented by several types of mills. One impact mill of about 8000 lb. an hour capacity was shown. Details were given of an air-swept ball mill and another manufacturer displayed a new type of mill employing two rows of balls and three grinding rings in which the weight of the grinding elements is carried on the grinding ring and not on the shaft. Details were given of a 40 ton per hour mill of this type which employs air separation and another smaller mill based on the same principle for about 2000 lb. an hour was also announced.

Great interest was manifested by the visiting engineers in the various exhibits of boiler manufacturers, several of whom displayed pressure vessels welded by electric fusion welding processes. Several of these drums were shown after having been tested with hydrostatic pressures as high as 3250 lb. per sq. in. One of these vessels was shown after having been tested to destruction and data were given on the characteristics of the metal and the stresses developed.

Welding processes of all kinds for power plant and industrial works were shown by several manufacturers who presented data on the ways in which the various methods could be used in the plant and shop together with methods of field testing.

Piping and valves for high temperature and high pressure work were shown in profusion. Examples of these were a 14-in. motor operated gate valve for 1350 lb. pressure, 1000 deg. F. Blowoff valves for pressures up to 2000 lb., gate valves and check valves for 2000 lb., several types of piping made of nickel alloys, and a complete line of forged stainless steel valves for all pressures. One large motor operated valve was shown that could be operated by voice or sound over ordinary telephone circuits with a television system for observing the operation of the valve at the remote operating point.

One of the outstanding features of the displays was the number of pieces of equipment to be supplied to power plant and industrial installations now under construction. Several valves of this type were shown together with two large induced draft fans. One of these was designed to handle 96,500 cu. ft. of gas per minute at 415 deg. 8.6 in. water pressure for the Hershey Chocolate Co. Another was for a boiler of 500,000 lb. of steam an hour capacity at Waukegan.

Several types of electric motors for industrial drives and power plant auxiliary drives were featured together with new and improved types of speed reducing equipment, also chain drives and gearing. Mechanical power transmission equipment such as belting, anti-friction bearings and accessories, received much attention.

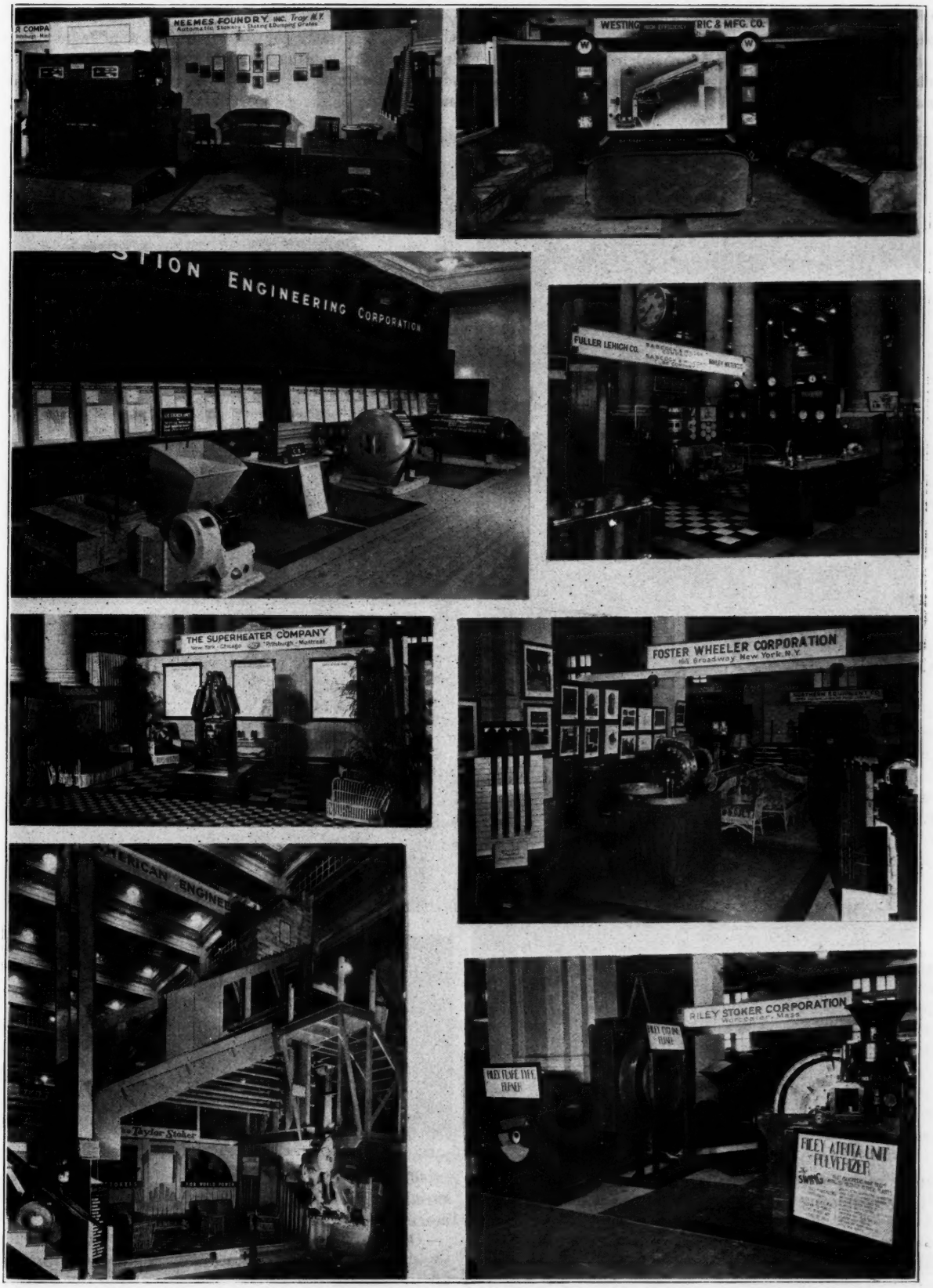
Prime movers included a small non-condensing steam turbine and several internal combustion engines. Among these were two Diesel engines, one a new type of rotary Diesel for airplane work, the other a high speed Diesel engine for stationary work. Gasoline engines up to 425 hp. in size were displayed for driving generating and pumping equipment.

Instruments of all types were exhibited in working arrangements. There were several new types of pyrometers, several improved models of CO_2 recorders and indicators, and some of the manufacturers of flow meters had developed new check seals for use with their manometers. A power type pressure transmitter for actuating instruments at long distances and including the Selsyn principle of transmission attracted much attention.

Several manufacturers exhibited new designs of water columns and gage glasses for high pressure work. One of these featured the loose window construction, another a high pressure gage using only mica and omitting the glass. Tubular water gages were shown for pressures up to 600 lb. and one design of water column employed an equalizer tube to reduce strains in the device. Water gages for locomotives to operate at 1700 lb. per sq. in. pressure were on display.

In the field of heating and ventilating, a unit air conditioner of 5000 c.f.m. capacity attracted attention, and other manufacturers had new types of steam and gas fired unit heaters. Of particular interest in this field was the unit cooler operating on the same principle as that of the unit heater except that a fan blows air across coils containing a refrigerant under the control of a special liquid level controller.

New devices for ash handling and dust collecting illustrated the increasing interest in this subject. One system employs an air swept valve through which dust from hoppers is drawn in a dry condition by the suction of a hydraulic ejector, which then discharges it


NEEMES FOUNDRY, INC. Troy, N.Y.
Automatic Stokers - Shaking & Dumping Grates
WESTINGHOUSE ELECTRIC & MFG. CO.
ENGINEERING CORPORATION
FULLER LEHIGH CO.
THE SUPERHEATER COMPANY
New York - Chicago - Pittsburgh - Montreal
FOSTER WHEELER CORPORATION
165 Broadway New York, N.Y.
RILEY STOKER CORPORATION
Worcester, Mass.
RILEY ATRITA UNIT PULVERIZER

TRENDS IN THE BOILER ROOM WERE EFFECTIVELY SHOWN BY STOKERS, PULVERIZERS, SUPERHEATERS AND BOILER DRUMS

for further disposal. There were also new types of centrifugal and cloth collectors for removing dust from flue gas and air.

A new model air preheater in which the elements are made of standard steel plates clamped together by a simple mechanical device was featured, together with new types of heat exchangers with floating head and removable tube bundles.

Construction of furnace walls of both refractory and water-cooled types showed the trends in these fields. Among these were armored walls for stokers, new methods of fastening cast-iron blocks to water wall tubes, methods of applying refractory facing tile to suspended walls, application of plastic cement to suspended arches, and use of an air-driven rammer for monolithic plastic construction.

Boiler feedwater controllers for all types of boilers from the small heating boiler to the largest power boiler showed improvements in design with several new models in evidence.

NEW TYPES OF REFRACTORIES, LARGE DRAFT FANS AND MECHANICAL DRIVE EQUIPMENT WERE ATTRACTIVE

There were several new types of steam traps, pressure regulating valves, packings, gaskets, and other accessories.

One display included a frequency controller for regulating speed of generating units to maintain constant frequency.

There was also shown a new type of smoke recorder and indicator in which a thermopile subjected to heat rays from a lamp was the actuating device.

In electrical control equipment a miniature switchboard was demonstrated to allow the concentration of all control switches and meters within arm's reach of the operator. Another manufacturer displayed a new method of mounting air break circuit breakers into steel cabinets with bus bars and other necessary switching equipment, the entire mechanism being racked out of the cabinet with all contacts broken for inspection and repair. Supervisory control equipment for remotely controlling the large amount of equipment over two line wires and a method of controlling the power demand of a system proved of interest to the visitors.

Boilers and Combustion Equipment

At the booth of American Engineering Co. was shown in actual operation a section of a new type Taylor stoker as designed for large boiler units. The hydraulic drive from a constant-speed motor was a feature, giving a constant horsepower of the drive over the speed range. This unit was of a type to be installed this year at Hudson Ave., to burn 58,000 lb. of coal an hour per unit, the stoker being 26 ft. 8 in. long. Individual pusher rod mechanism was shown, new type of tuyeres and clinker grinder. Details of this design have been previously published in Power Plant Engineering.

On a model of its new stoker, Westinghouse Electric & Mfg. Co. called attention to improvements in tuyeres in which two thin tuyeres are sometimes used instead of a thick one in certain special cases to reduce clinkering. This procedure provides more air streams, cools the clinker and keeps it from sticking.

New pulverized coal burner of turbulent type was shown by Riley Stoker Corp. It has divided coal outlets, adjustable secondary air dampers and is designed to produce high turbulence and short flame for normal capacities of 8000 lb. of coal an hour, maximum 12,000 lb. an hour. New features on the Riley Atrita include a redesign of fan and rotor to decrease the width, with an all steel welded housing for both instead of the former separate housing. Improvements on the Jones side dump stoker include new type of alternate moving and stationary grate, side dump with levers at stoker front, new lever actuating mechanism and Riflex drive for speed control as recently described in Power Plant Engineering.

At the booth of Combustion Engineering Corp. was shown a fusion welded drum tested by hydrostatic pressure up to 3250 lb. per sq. in. The elongation of the drum which was 34 in. diameter, 98 in. long with 1-in. shell and 1½-in. heads, was shown and technical data presented on the results of the test and an analysis of the entire operation. One of the pressed heads for installation by Brooklyn Edison Co., a 54-in. dia. shell, 2½ in. thick, was also displayed.

For firing heating boilers and small industrial boilers from 25 to 150 hp., the C-E stoker unit was exhibited. This has agitated hopper to prevent arching, laterally agitated grate bars, silent duralumin fan, enclosed motor, screw feeder, ash dumping grates and other features.

The C-E Economizer, fin-tube type, as recently described in Power Plant Engineering was displayed. This consists of horizontal fin tubes connected at the ends by return bends outside the path of the gases, a recent improvement being the use of a ball joint between bends and tubes.

New design of air preheater was shown by Prat-Daniel Corp., in which the heating elements are made of standard steel plate held at the edges by a channel and two bars, the whole held by screwing up a conical wedge nut. No frame is used, all expansion being taken up in the ductwork, it is stated. A Type II Thermix ejector stack for handling high temperature or corrosive gases, using an external fan out of the path of the hot gas, was demonstrated by a transparent model. The Thermix Type IV dust collecting fan was also featured.

At the booth of Babcock & Wilcox Co. data and photographs as well as test specimens were exhibited, covering the company's new fusion welding process as recently described in detail in Power Plant Engineering. Many examples of equipment made of Nirosta metal were displayed, such as heat exchangers, pipe fittings, return bends and so on. Specimens of electric resistance butt welded tubing were also shown.

By drawings and photographs, Fuller Lehigh Co. showed the details of its new type B pulverizing mill. This is an air separation mill, grinding being done by two rows of balls rolling between three horizontal rings. The middle ring drawing the balls revolves, driven from the main vertical shaft; pressure of balls and rings is varied independent of mill speed. No lubrication is needed in the grinding zone. The mill runs at constant speed and is designed for a wide range of capacity. It is built in sizes up to 40 t. an hour. A new type C mill for about 2000 lb. an hour capacity for smaller installations was shown. This is built on the same grinding principle as the type B mill but it has only one row of balls.

New methods of electric fusion welding for pressure vessels were exhibited by M. W. Kellogg Co. One feature was a vessel fabricated with a body of seamless steel, with rolled steel ellipsoidal heads, the girth welds and nozzle fabricated by the company's welding process. Another interesting item was a vessel that had been tested to destruction by hydraulic pressure. This was a tank 5 ft. long, 48 in. diameter, form rolled of 1¼-in. steel plates with two dished heads. The tank burst when a hydraulic pressure of 3250 lb. per sq. in. had been reached, the stress in the shell plate on bursting being calculated as 62,400 lb. per sq. in.

Model of a 1400-lb. semi-vertical boiler with Elesco superheaters, as it will be installed at Ford Motor Co.'s plant, was shown by the Superheater Co. This showed the arrangement of superheater tubes between boiler tube banks and method of connecting to headers. A large drawing showed the construction of the superheaters at the new Raritan River plant at Sayreville, with the superheated steam headers outside the path of the gas, one header being outside the furnace wall entirely.

Foster Wheeler Corp. featured a new design of heat exchanger of the two-pass counter flow type with floating head and removable tube bundles, baffles welded and tube sheets split to pass the baffles. The Hardinge unit mill system was shown with new features in the form of an automatic cutoff damper, solenoid controlled, at the exhauster, arranged to close when the mill shuts down to seal the duct and open the exhauster to atmosphere.

This is to prevent flareback and provide pure incombustible air to the exhauster and burner during the last few revolutions of the exhauster, to eliminate explosion dangers. Another automatic cutoff damper is placed between hot air duct and mill and an automatic tempering duct at the mill entrance. On the new type B armored furnace wall, cast-iron blocks fitting around the tubes form a continuous surface. The blocks have "television" to show the remote operator just what the position of the valve is at any time.

For pressure of 1350 lb. and temperature of 1000 deg. F., a 14-in. motor-operated gate valve was displayed by Chapman Valve Mfg. Co. This was made of Chapman chrome tungsten steel, tensile strength 125,000 lb. per sq. in.

De Florez remote manual control system for operat-

BOILER INSTRUMENTS AND ACCESSORIES, DIESEL ENGINES AND GAS APPLICATIONS ATTRACTED MUCH ATTENTION

rounded sides and a toggle clamp and spring washer holds the joint firm in spite of any tube movement.

Piping and Valves

For remote control of valves, the Limitorque Corp. displayed a large valve operated by a Limitorque control actuated by the human voice or other sound over ordinary telephone circuits, with a system of signals or ing valves, as described recently in Power Plant Engineering, was a new product shown by Brown Instrument Co.

Yarnall-Waring Co. featured its new cylinder-guided expansion joint, with all parts inside the diameter of the flange, chromium-plated steel sliding sleeve cylinder guide with stuffing box integral and internal limit stops. There was also the complete line of tandem blowoff

valves for pressures up to 2000 lb. per sq. in. and hydraulic valves up to 5000 lb.

Walworth Co. demonstrated its new Walco pipe wrench, consisting of four parts: bar, jaw, nut and spring. Jaw housing is forged integral with the bar; the jaw is designed for hard use with threads having rounded crests to resist damage and jamming. The spring, allowing double action on the jaw, can be removed and replaced without tools. The wrench is designed so it will take a firm grip quickly but will not lock on the pipe. Tests of the strength and gripping qualities were exhibited.

Henry Vogt Machine Co. showed a new type of globe and gate valve for 600 lb. in the 6-in. size, with integral flange, steel or stainless steel trim. This type was formerly made only up to 1 in. It also announced a complete new line of forged stainless steel valves, for uses where corrosion is a factor, for any service or pressure where a forged valve is required.

Dardelet Threadlock Corp. showed new applications of its self-locking thread, such as on pot-heads, electrical equipment, the Bristo set screw and so on.

Mason Regulator Co. displayed new types of stainless steel poppets for balanced valves, also a new No. 338 single-seated diaphragm valve for dead end service.

Midwest Piping & Supply Co., Inc. showed test specimens of joints tested by pulling apart, to allow comparison of the action of Globack and standard Van Stone joints under test, and giving detailed data on the tests, with photo-micrographs of the specimens.

Check valves and gate valves for 2000 lb. working pressure, to be supplied to the new power plant of Philip Carey Co. were displayed by Schutte & Koerting Co. Motor-operated single-seated Venturi reducing valve of latest construction, as described in Power Plant Engineering recently was also on display together with new duplex strainers operated by a single-plug cock.

Regulating valves with rotary shaft were displayed in new designs by H. Belfield Co. The rotating stem is of stainless steel supported in large bronze bearings. Bushings are interchangeable so the lever can be installed on either side. New Equipoise valve for high velocities or pressures has balanced disk to eliminate side thrust, one piece packing chamber and front stem bearing of cast bronze. These valves are supplied in iron or steel for various pressures.

E. B. Badger & Sons Co. showed its new riser expansion joint, employing a sylphon bellows for low pressure heating system risers. A new construction on copper hot water storage tanks was also shown by a tank with heads brazed instead of riveted.

Fittings for fire lines, for working pressures of 350, 500 and 800 lb. were new products shown by Stockham Pipe & Fittings Co.

Pipe Tools

New pipe tools, some of which have been recently described in Power Plant Engineering, were shown in operation by the Borden Co. These included the Beaver 4-poster, with improved dies upright posts, ratchet drive ring on head and heavy construction. The square-end cutter for 2½ to 4-in. pipe, easily centered on pipe by V-blocks with stationary driving pinion in front was another feature. The Beaver 3-way tool had electrically heat treated square die segments, ample chip clearance capacity ⅜ in. to 1 in. A new head for No. 3 ratchet die stock, a new hand operated wheel cutter, and Universal motor on the Power Drive were other features.

Toledo Pipe Threading Machine Co. had on display its new No. 999 portable machine. Driven by a ½-hp., 110-v. universal motor, it has cutting head of special design with 4 circular cutting blades, separate die heads for each size thread, centrifugal oil pump, safety function gear, heavy 3-jaw universal clutch, all control centralized in forward and reverse switch and other features. It is made for ½ to 2-in. pipe.

Prime Movers

New small mechanical-drive noncondensing steam turbine for driving pumps, fans and similar industrial equipment was featured in the General Electric exhibit. The new turbine is built only as a single-stage machine and has two rows of revolving buckets. It follows the design of the standard line of G.E. mechanical-drive turbines. The wheel casing is split horizontally for easy access to the internal parts and the steam and exhaust pipes are connected to the lower half of the machine. A new centrifugal governor with weights pivoting on knife edges is designed to operate with little friction and provide proper speed regulation.

Additional equipment to be displayed included an electric gage, an outdoor switch house equipped with a closing feeder and an oil circuit breaker, also a 3-section circular type miniature switchboard. The latter is to make possible the observation of a larger number of instruments and controls by one man standing before it.

Motors included in the display were: A 15-hp., 1200-r.p.m., 220/440-v., 3-phase, 60-cycle, single end ventilated totally enclosed fan cooled induction motor; a unity power factor, 30-hp., 600-r.p.m., 220-v., 3-phase, 60-cycle synchronous motor; a 5-hp., totally enclosed, fan-cooled, induction motor; a 5-hp. standard induction motor; a 1½-hp., sleeve bearing motor; a 1-hp., 3600-r.p.m., 60-cycle, drawn shell, low torque design motor with capacitor; a ¾-hp., 1200-r.p.m., high torque capacitor motor with capacitor; a 5-hp., 1800-r.p.m., single-end ventilated induction motor; a 10-hp., 1800-r.p.m., 220-v., 3-phase, 60-cycle, horizontal ball-bearing motor. Control apparatus included a magnetic switch, high voltage compensator, a pole changing switch, and an exhibition switch panel containing various switches. A colorama lighting set controlled by two thyratron vacuum tubes complete with a timing unit was also on exhibition. Colorama is the method of painting the walls of a room with light so that colors and patterns may be changed instantly and for hours at a time through the use of a series of covers and flutes concealing incandescent lamps.

Packard-Diesel aircraft engine of 225-hp., 1950-r.p.m., was a feature of the Texas Co. display. It is a nine-cylinder, four-cycle, air-cooled static radial engine, of the solid injection type, weighing 2.26 lb. per hp. It has magnesium barrel type one-piece crankcase, forged chrome nickel molybdenum crankshaft, aluminum pistons, forged chrome molybdenum steel cylinders, independent plunger type fuel pump on each cylinder and single valves with venturi for both inlet and exhaust. Here also was shown El Glykol, a new liquid for water-

proofing any surface to prevent staining, disintegration, efflorescence and provide waterproof primer under paint.

I. P. Morris & De La Vergne, Inc. displayed its new high speed Diesel engine in a 300-hp., 750-r.p.m. model. This has aluminum pistons, fuel transfer pump, solid fuel injection, two fuel oil filters in series, nickel cast-iron removable liner, pressure lubrication, silent roller chain for camshaft drive and other features.

Water Columns

Water columns and gage glasses for high pressure of loose window construction, as recently described in Power Plant Engineering were displayed in operation in actual equipment by Diamond Power Specialty Corp. In this construction, the flat type gage glasses are between mica sheets and the glass is virtually loose, acting only as support for the mica. The design is to prevent straining the glass by tight clamping. The glass is not under pressure higher than the steam pressure. These columns and gages are for all high pressure service.

Adjustable split gland water gage with tubular glass, for 600 lb. pressure, was a new product of Ernst Water Column & Gage Co., equipped with a new type of guard consisting of glass panels with an inner lining of punched steel plates.

Reliance Gage Column Co. showed a new design of water column for pressures up to 1500 lb. in which mica windows are used on the flat type water gage, without glass. Flat glass type columns with short glasses, for 1700 lb. pressure were shown as built for the new high pressure locomotives of Canadian Pacific Railway and New York Central Railway. This exhibit was at the booth of Paul B. Huyette Co., where also were shown new products of Hays Corp. A new square type boiler panel board included a signal system set to flash a red bullseye for any predetermined low value of CO_2. A new Hays combined CO_2 indicator and draft indicator, both reading on the same instrument face, was a feature of this panel.

EXHIBITS OF HEATING EQUIPMENT, VARIABLE SPEED DRIVES AND SOUND-DEADENING MATERIALS

For pressures of 600 to 700 lb. per sq. in., Wright Austin Co. displayed a new water column with forged steel mounting pieces. These are connected by a tube, welded into the mounting pieces and this tube carries water and steam just as the gage glass does, the object being to equalize strains in glass and column.

Improved methods of installing condenser tubes were shown by Scovill Mfg. Co.

Bundy Steam Trap Co. showed improvements in several of its traps. The complete line from ½ to 3 in. is now equipped with the A type bowl with improved stuff-

ing boxes and all parts cast integral. Capacities range from 1500 to 24,000 lb. an hour.

New traps and improvements on existing units were shown by Sarco Co., Inc. A new combination float and thermostatic trap was shown for pressures up to 125 lb. This has new piston type valve, with head and renewable seat of stainless steel, actuated by ball float. The thermostatic element is longer and heavier and is protected by a shield.

Kaye & MacDonald, Inc. displayed the new K-Master inverted bucket and ball float steam traps. In both, the valve mechanism is outside the trap and works vertically.

Piston-operated trap for handling large volumes of condensate or other liquids at high working pressures was a new product shown by Armstrong Machine Works. These traps can be made of forged steel if necessary or desirable. They incorporate a new type of leverage mechanism. Liquid entering the inlet fills an upper chamber, passes down a tube to a lower chamber where as the level rises, a bucket rises, opens a ball type pilot valve which operates a larger piston valve, permitting the trap to discharge. The piston valve is cushioned without using springs and without metal to metal contact.

Ash-Handling

Allen-Sherman-Hoff Co. showed the wind-swept valve for handling ash or dust and the hydrovactor. The wind-swept valve on the bottom of a dust bin has ports that, when opened, permit the suction from the hydrovactor to pull dust along dry; the dust is then swept into the stream of water from the hydrovactor and discharged, as recently described in Power Plant Engineering.

New models of soot blowers were exhibited by The Vulcan Soot Cleaner Co., showing improved valve disks, improved spring suspension and wall sleeve with ball joint to care for expansion of setting. Blowing elements are made of a new high-temperature alloy designed to eliminate grain growth.

For use with pneumatic ash disposal systems to separate dust from the air before it goes to the exhauster, Girtanner Engineering Co. showed a new dust collector.

Working model of the smoke and soot washer made by American Smoke and Soot Washer Co., Inc., as recently described in Power Plant Engineering was displayed.

Moulded graphite products for industrial uses were shown by Joseph Dixon Crucible Co. These included motor and generator brushes, resistors, heating units, welding equipment, lubricating plugs, clutch rings and many others.

Regulating Valves

Tension type thermostats will be applied to all its regulating equipment after January 1, it was announced by Northern Equipment Co. These were shown, together with improvements in parts of valves and a complete working model of the Copes excess pressure control using the type SS valve as described in Power Plant Engineering, was shown in operation. The new type OT Copes regulator for h.r.t., Sotch marine, oil field and similar boilers was displayed. On this device, the thermostatic element is of two short tubes connected at an angle by a heavy bronze return bend, to save space and give the operating effect of a single tube.

Boiler water feeder of new design for heating boilers was featured by Watts Regulator Co. In this device, a float rising and falling with water level in the boiler actuates a feed valve to regulate the flow of feedwater.

Webster Boiler Protector was a new product shown by Warren Webster & Co. It is a hydraulically operated valve for feeding of water to low-pressure heating boilers to protect against low water level. A float actuates a small pilot valve which produces a pressure difference, actuates a sylphon bellows, which in turn actuates the main valve. The bellows multiplies the force and the pilot valve is made so it cannot be stuck closed.

Duplex Water Feeder for boilers at pressures up to 100 lb. and capacities up to 4100 lb. of water an hour was a new product shown by Kieley & Mueller, Inc. The complete valve, cast as part of the bottom plate of the feeder, with a strainer around the valve orifice, is actuated by a float. Cold water enters below the valve seat. The discharge side of the valve is sealed with hot water. Valve point and seat are of monel metal. An overflow valve controlled by a float, discharges excess returns to waste.

New design of double suction condensation pump was exhibited by Nash Engineering Co. In this unit pump and motor are one structure, the pump impeller overhung and the casing supported by a bracket from the motor.

La Bour Co. showed a new automatic suction control valve for use when one pump is connected to several sumps; the valve is to open automatically and control the water level in each sump, eliminating necessity of a separate pump for each sump. The valve also can control level of water in the various sumps regardless of their elevation.

Heating Equipment

L. J. Wing Mfg. displayed a new extended surface heating element for unit heaters and other uses, consisting of return bend tubes with fins pressed on them. These can be made for either high or low pressures.

Zone control heating system of new type was displayed in operation by Illinois Engineering Co. This can be either automatic or manual, a panel in the engineer's office giving full indication of conditions. It was shown as used to control a battery of unit heaters, turning steam on at reduced pressure through a special control valve, starting the fans, then shutting down in proper sequence by hand or by temperature control of a mercury switch, with tell-tale lights on the control board.

New unit cooler was displayed by Grinnell Co., a device for blowing air over cooling coils and directing it about in a room. It consists of extended surface cooling coils to be used either with direct expansion ammonia, brine or other refrigerants, a motor-driven fan behind the coils and a liquid level control device specially developed to hold the refrigerant at the proper level in the coils.

American Blower Corp. had on display one of three special fans built for Hershey Chocolate Co. It was a No. 9 double inlet Sirocco fan, 96,500 c.f.m., 200 hp.

drive, 8.6 H_2O pressure, 695 r.p.m. gas temperature, 415 deg.

New Model B Breezo-Fin unit heaters and gas-fired unit heaters were featured by Buffalo Forge Co. The Breezo-Fin heater has Aerofin heating element, die-stamped fan and bracket, adjustable discharge louvers, clip hangers, rugged casing, light weight. The gas-fired unit has automatic gas shut off, when motor-driven fan stops, temperature controls, safety shutoff on failure of gas supply, output of about 125,000 B.t.u. an hour. Remote or thermostatic control may be applied.

Automatic frequency control for generating units was demonstrated in full size panels by Leeds & Northrup Co. In this controller, the mechanism of the controller, actuated by variations in a frequency bridge, acts on pilot motors that in turn act on the governor mechanism of the turbine, adjusting its speed by small amounts so that the generator it drives will maintain a constant frequency. Another new device was the smoke recorder, in which heat from the flue gas is directed by a lens onto a thermopile; smoke in the flue gas will vary the amount of heat and thus will vary the e.m.f. of the thermocouples, the variations being suitably amplified and recorded.

Republic Flow Meters Co. called attention to its new control pyrometer. It is an on-and-off control, equipped

STEAM TRAPS, VALVES, PIPE TOOLS AND WATER COLUMNS INTERESTED THE VISITING ENGINEERS

with a mercury contactor switch with current capacity of 50 amp., 220 v. or 60 amp. at 110 v. actuated by a selector system and small motor that moves it to the proper position.

New electrical type pyrometer, with indicator and rotary switch for obtaining readings from several points, the whole incorporated in one instrument was displayed by Bristol Co. New models of flush type recorders for panel mounting were also featured.

Draft gage with 34 pointers for use with a large stoker to measure each windbox was shown by Ellison Draft Gage Co. A check seal for pointer draft gages was also shown. It is built so that in case of excess suction beyond the gage range, the valve closes off the oil pipe and vents the bell, preventing loss of oil.

At the booth of Bailey Meter Co. the chief feature was a new power type pressure transmitter actuating a large boiler room pressure gage hung over the booth. This transmitter has been developed to transmit indications to instruments at long distance. It employs a balanced piston mechanism, with oil pressure on the bottom and a weight on top of it in the form of a mercury pot. Variations in pressure unbalance the system, cause ports on the piston stem to open and permit oil pressure to actuate a bell which in turn actuates a selsyn motor through suitable linkages. The selsyn motor at the transmitter then actuates a selsyn at the receiving end.

Simplex Valve & Meter Co. showed its water meter equipped with the new Elinco remote indicator, actuated by devices operating on the principle of the synchronous motor.

Self-contact recording potentiometer pyrometer was a new device shown by Uehling Instrument Co. The potentiometer of this instrument is separate from the recorder and indicator, a single control box actuating as many as four recorders in different locations, each measuring a different temperature. On the recorder, a motor operates to adjust the pen on a clock-driven chart and also actuates a translucent endless belt 2 ft. long moving behind the pointer to give temperature indication.

New model of the Ranarex CO_2 recorder and indicator was displayed in a working exhibit by Permutit Co. The fundamental principle, of course, remains, but the air and gas impulse wheel indicator and recorder mechanisms are assembled on one plate and the motor, seamless belt and other parts on another plate, both easily removable from the case.

The rate of flow control box of the Permutit continuous blowdown system was also displayed. This is to control flow of blowdown water through a heat exchanger to maintain a proper concentration in the boiler. For feeding chemicals in water treating systems, two new chemical feeders were shown, one an electrochemical device working direct from a water meter, the other for constant feed. Another new product was the Permutit household water softener.

A three-pen recorder for temperatures, pressures and the like, as recently noted in Power Plant Engineering, was shown by Taylor Instrument Cos.

Foxboro Co. displayed integrating flow meters for pressures of 2000 and 5000 lb. per sq. in.

Builders Iron Foundry exhibited a new type of Venturi tube, designed for high pressure service. The Venturi section was welded in a length of steel tubing; inlet and throat pressure chambers were also welded to the tubing. Straightening vanes were welded in the tube to improve flow conditions. The entire tube, so constructed, was built for welding in an all-welded line and for any high-pressure service—boiler feed, oil, gasoline. For use with this special tube, a type M Register-indicator recorder was shown. Information was given on the uses that have been made of Venturi meters on boiler feed lines up to 1625 lb. per sq. in. pressure.

Improved pressure recording and indicating gages were featured by The Ashton Valve Co. This gage has an indicating hand and large-figured dial outside the circular recording chart and concentric with it, to enable the operator to read the pressure from a distance.

Variable speed transmission of totally enclosed type was a new product shown by Reeves Pulley Co. A new

ONE OF THE DISPLAYS OF LUBRICATING OILS

vertical model with adjustable motor base was also featured and attention was called to new compact designs.

P. I. V. Gear, a positive, infinitely variable speed transmission of new design was displayed by Link-Belt Co. This consists of two pairs of opposed conical disks, with radial teeth in the conical faces and a self-adjusting chain engaging these teeth and transmitting power from one to the other. By varying the distance between the disks of each pair, the chain rises between one set of disks and descends between the other, thus permitting smooth and extremely small variations of speed.

Attention was called by S. Obermayer Co. to its new equipment for installation of Ramtite plastic monolithic furnace lining. This equipment consists of an air-operated rammer for which compressed air is supplied by a portable air compressor driven by a gasoline engine. Also, the company showed how its products are now supplied in 100-lb. cartons.

Carborundum Co. showed new types of carborundum facing tile as applied on a Bigelow suspended wall in boiler furnace construction.

New use of Adamant fire brick cement in installing and maintaining suspended arches in boiler furnaces was demonstrated on an actual arch by Botfield Refractories Co.

Pourinsul and Moldit-B, especially adapted to steel plant work were announced as new products by Refractory & Engineering Corp.

True Blue boiler treatment was featured by Economy Lubricating Co. This is an internal treatment for preventing scale, pitting, corrosion in boilers by depositing a coating of heat conducting film around tubes and shell.

Dearborn Chemical Co. exhibited a new product, Lo-Ac. This is a highly concentrated, water soluble material used in grinding and cutting compounds. When so used, it remains on the metal and forms a rust preventive coating.

International Nickel Co., Inc. featured in its display the fundamental types and uses of various nickel alloys such as nickel cast iron, nickel bronze, Lo-Ex or nickel aluminum, monel metal, Ni Resist, a nickel-copper-chrome iron, also alloys of nickel with copper and manganese and use in steel. Products using these alloys, as fabricated by many manufacturers, were displayed.

Absorbit, a soundproofing material for walls and Absorbophone, a soundproofing material for floors, were two new products shown by Korfund Co., Inc. Absorbit is a corrugated material with air spaces, the whole coated with asphalt. Absorbophone is of cork with granulated cork filler and is also covered with asphalt, which aids in deadening the sound.

Tidewater Oil Sales Corp. showed a new steam turbine oil, made by a special process, to give high resistance to emulsion, low acidity and low carbon residue and to stand up under high bearing pressures and temperatures.

Packing for high superheats and hot oil, Style 250, was shown by Crane Packing Co. This is intended for steam, air, gas or oil, where the temperatures range from zero to 1500 deg. and pressures up to 2000 lb. Here also was shown the Franklin condenser tube cleaner; the slug equipped with a spring bronze cleaner designed to expand with the rubber slug under water pressure fitting the tube tightly.

Crandall Packing Co. exhibited Travgargran for hydraulic installations and Crandite rings for hot water service.

Buttonhole tape for gaskets was a new product introduced by Garlock Packing Co. It is made of two parallel courses of folded asbestos cloth joined by a single ply of bonding fabric. Insertion of a knife blade between the two sections cuts the bonding fabric, forming a button hole that slips over the stud.

Sharples Specialty Co. gave details of a new completely automatic horizontal centrifugal machine for chemical and industrial work.

Keystone Lubricating Co. displayed its new Pneuma-Lectric Automatic lubricating system, as recently described in Power Plant Engineering. The distributing devices have been made more compact and a full size equipment was shown to demonstrate flow of grease to bearings in sequence, actuated by a clock, with automatic by-pass devices for shut down units.

I-T-E Multumite switchboard was displayed by I-T-E Circuit Breaker Co. in a full size equipment. This showed the breaker compartment, pantagraph for racking out the panel, at the same time breaking all contacts, interlocks to prevent closing breaker with door open, remote solenoid control, disconnects for line, load and control circuits.

C. E. Allen Appointed Commercial Vice President for Westinghouse

CLAXTON E. ALLEN, formerly manager of the Southwestern District of the Westinghouse Electric and Manufacturing Co., was elected a commercial vice president of that company at a recent meeting of its Board of Directors.

Mr. Allen, who has been associated with the Westinghouse Company since 1909 is a native of Virginia. After attending high school in that state, he was graduated with the degree of Bachelor of Science in electrical engineering from the Virginia Polytechnic Institute in 1901. His first position with Westinghouse was as head of the transformer division of the detail and supply department. Three years later he was appointed assistant to manager of that department. For a short time in 1915 he was attached to the sales department of the New York District Office and then was made manager of the supply division and central station division of the Chicago Office, which position he held until 1922 when he was appointed manager of the St. Louis District Office. Mr. Allen is a Fellow of the American Institute of Electrical Engineers and has been vice-president of the St. Louis Electrical Board of Trade. He has assumed his new duties with headquarters in East Pittsburgh.

News Notes

BABCOCK & WILCOX Co. will bring the plant facilities of the Fuller-Lehigh Co., Allentown, Pa., to Barberton Feb. 1, according to a recent announcement.

CHANGES in its organization personnel as follows are announced by the Lincoln Electric Co. of Cleveland, Ohio: S. H. Taylor, Jr., succeeds W. S. Stewart in charge of Pacific Coast business wtih headquarters at 812 Mateo St., Los Angeles, Calif.; Mr. Stewart is now district manager of Cleveland, Ohio, territory. L. P. Henderson is manager of the San Francisco office and E. J. Pfister is district manager of Kansas City district with offices in 405 R. A. Long Bldg. The Philadelphia office, in charge of D. C. Anderson, has removed to the Commerce Bldg.

FIRESTONE DE LA ARGENTINA, a subsidiary of the Firestone Tire & Rubber Co., has authorized Dwight P. Robinson & Co., of Argentina, Inc., a division of United Engineers & Constructors, Inc., to build a new tire manufacturing plant and power house at Buenos Aires, Argentina. Construction work on the new plant will begin at once.

ANDERS & REIMERS announces the removal of its offices to 712 Columbia Building, Prospect Ave. at E. 2nd St., Cleveland, O.

ILLINOIS STOKER Co., Alton, Ill., announces the establishment of an eastern office at 30 Church St., New York City, in charge of Alex Girtanner.

SECOND SUB-STATION erected by the Rockford (Ill.) Electric Co. within recent months to meet increased calls for service, will soon be completed at Ninth St. and Harrison Ave., F. G. Barnett, manager of the electric division has announced. The new unit will have 6000-kw. capacity and will relieve the demands upon the substation at Ninth St. and Twenty-third Ave.

CENTRIFIX CORP., Cleveland, Ohio, announces that the Wyman Engineering Sales Co., Chamber of Commerce Bldg., Cincinnati, has recently taken on its account in that territory.

DAYTON-DOWD Co., Quincy, Ill., announces the appointment of J. B. Downey, 2944 North Second St., Phoenix, Arizona, as its district sales representative for the State of Arizona.

E. C. GOODRICH, Passaic, N. J., for many years chief engineer of the Okonite Co., died suddenly on Dec. 1. He was an active member of N. A. P. E., Passaic, No. 11, and was well known among engineers in northern New Jersey.

DAMPNEY CO. OF AMERICA, Hyde Park, Boston, Mass., announces that on Dec. 1, its agency agreement with D. H. Skeen & Co., Chicago, was discontinued and that it now maintains a direct company branch office, to serve customers in the Middle West, in the Monadnock Bldg., 53 West Jackson Blvd., Chicago, Ill.